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Interruption of People in Human-Computer Interaction: A General Unifying Definition of Human Interruption and Taxonomy

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User-interruption in human-computer interaction (HCI) is an increasingly important problem. Many of the useful advances in intelligent and multitasking computer systems have the significant side effect of greatly increasing user-interruption. This previously innocuous HCI problem has become critical to the successful function of many kinds of modern computer systems. Unfortunately, no HCI design guidelines exist for solving this problem. In fact, theoretical tools do not yet exist for investigating the HCI problem of user-interruption in a comprehensive and generalizable way. This report asserts that a single unifying definition of user-interruption and the accompanying practical taxonomy would be useful theoretical tools for driving effective investigation of this crucial HCI problem. These theoretical tools are constructed here. A comprehensive analysis is conducted through the existing literature. Theoretical constructs from several relevant but diverse fields are identified and discussed. A unifying definition of user-interruption is synthesized. This new definition is supported with an array of postulates, assertions, and a taxonomy of human interruption to facilitate its practical application.

14. SUBJECT TERMS

HCI	Discourse	Politeness	Interruption	User-interface	Situational awareness
Dialogue	Cognition	Psychology	Multitasking	Mixed-initiative	Intelligent user interface
Interrupt	Taxonomy	Linguistics	Man-machine	Human attention	Human-computer interaction
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EXECUTIVE SUMMARY

AIMS AND OBJECTIVES

This report identifies a mission-critical but currently neglected topic and proposes new fundamental theoretical tools for research. This critical but ignored research problem is the interruption of people during their human-computer interaction (HCI). This report discusses the importance and timeliness of this issue and presents new and fundamental theoretical tools for general research on this topic. These new theoretical tools are (1) a unifying definition of human interruption and accompanying postulates and assertions and (2) a taxonomy of human interruption.

After reading this report, the reader should understand the importance of human interruption as a research topic, and recognize the new theoretical tools provided by this report and their potential application for HCI research and development.

OVERVIEW

User-interruption has existed as an unexplored and relatively innocuous HCI problem in older, traditional computer systems. However, modern computer systems often implement intelligent software technology that escalates this HCI problem into a mission-threatening complication.

Modern, more intelligent, systems have the adverse HCI side effect of greatly increasing user-interruptions. Many kinds of intelligent systems have the important advantage that they can do work without constant human control. This frees the user to do other things while the system is working. Computer systems with this kind of intelligent software allow the user to more easily perform multiple tasks at the same time (user "multitasking"). However, this advantage has a detrimental side effect — whenever an intelligent system requires direct interaction with its user, it must first interrupt its user away from the task they are performing. Interrupting the user can have serious, even life-threatening consequences.

This HCI problem of user-interruption will worsen in the future as computer systems become more intelligent. Many research and development groups, including those in the Navy (e.g., Navy Center for Applied Research in Artificial Intelligence (NCARAI)), are currently investigating artificial intelligence (AI) technologies that will increase the semiautonomous capability of intelligent systems. However, application of these new AI technologies will also increase the mission-threatening hazards caused by the side effect of user-interruption. Therefore, it is important that we investigate methods to counteract the problems associated with user-interruption by intelligent computer systems.

We know from previous investigations that people have cognitive limitations which restrict their ability to work during interruptions. These limitations can adversely affect people's performance on critical tasks. For example, an interruption of a commercial airline crew before takeoff contributed to their subsequent crashing of the plane. A Northwest Airline crew was preparing to fly out of Detroit Metropolitan Airport. The crew began the preflight checklist properly but were interrupted by Air Traffic Control before they verified the status of the airplane's flaps. The flaps were not down, as required. After the interruption by Air Traffic Control, the crew allowed other issues to distract them from resuming their checklist. Other

distracters included confusion about which taxi-way to use because of a change in taxiing directions and delayed reports of weather and runway conditions. The crew took off without finishing their checklist. They never checked to see if the airplane's flaps were in the correct take-off position — they were not. A flight emergency occurred shortly after takeoff. If the crew had understood their situation, they could have successfully become airborne without flaps. However, the crew had also received a windshear alert. When the emergency occurred, the crew mistakenly interpreted the problem as windshear instead of flap position and crashed the plane (National Transportation Safety Board 1988).

The phenomenon of interruption is common in many different contexts. However, there is currently no unifying treatment of the interruption phenomenon in the literature. Therefore, the currently available articles relevant to human interruption are not in a form that is generally usable to HCI designers. Authors working in different context domains have published many different definitions and perspectives of the phenomenon of interruption. This report discusses these different definitions and perspectives from the literature and proposes a common context for discussing the strengths and weaknesses of each.

Authors in the field of HCI have not yet published effective user interface design methodologies for managing the problems associated with user-interruption in intelligent computer systems. In fact, no general definition of human interruption exists. This lack of a general unifying definition of interruption means that it is currently difficult to generalize research results across fields. Instead of being able to use the published findings of others, each HCI research/development team must invent its own ad hoc solution to the problem of interrupting the user. However, experience with ad hoc solutions has shown that the problems of user-interruption are complex and not easily solved. Researchers need to discover powerful and generalizable theoretical tools that will allow HCI designers to successfully address this complex problem.

This report makes a significant contribution by providing the first unifying definition of the interruption phenomenon with an accompanying taxonomy for its practical application. This unifying definition is supported by a broad review of theory.

MOTIVATION

To provide essential theoretical products for addressing an increasingly critical HCI design problem for intelligent computer systems.

ORGANIZATION

The report introduces the HCI problem of user-interruption and discusses its importance and timeliness, and it creates a general definition of the interruption phenomenon by accomplishing the following:

- analyze existing literature for useful information relevant to the interruption phenomenon;
- identify several theoretical constructs of interruption that describe declarative and procedural information contained in the current literature about all aspects of the interruption phenomenon;
- use the results of this broad analysis to identify high-level theoretical concepts, which generalize across research domain boundaries;
- synthesize a new and unique unifying definition of the interruption phenomenon from these general, cross-domain concepts; and
- synthesize supplementary theoretical tools, e.g., postulates, assertions, and a taxonomy of human interruption, to augment the unifying definition and to facilitate its practical application.

INTERRUPTION OF PEOPLE IN HUMAN-COMPUTER INTERACTION: A GENERAL UNIFYING DEFINITION OF HUMAN INTERRUPTION AND TAXONOMY[1]

1 INTRODUCTION

Aims and Objectives

This section introduces the topic of this research — interruption of the user in the context of human-computer interaction (HCI). Further, it discusses why this problem is important and timely and describes the approach chosen for this research. After reading this section, the reader should be familiar with the topic of human interruption and understand the scope of this report.

Overview

"Know thy user" (Hansen 1971) is a useful maxim for HCI design. In the current HCI design of intelligent systems, however, it seems that this maxim is being replaced with another maxim — "monopolize thy user." There is no ready solution for the growing HCI problem of user-interruption This lack of guidelines has resulted in modern systems that inadvertently badger users into singular devotion.

Computer system designers increasingly employ artificial intelligence (AI) technologies. This infusion results in "intelligent" computer systems that provide a degree of semiautonomy in accomplishing complex tasks. Applied AI technology can be very useful. Semiautonomous systems, however, have different user interface requirements than traditional, no-autonomy systems — they do not require constant user attention. The user must only intermittently interact with the computer system, because some of the time, the system is working on its own.

This new style of intermittent HCI causes a dramatic increase in the side effect of user-interruption. When a semiautonomous system must communicate with its user, it must first interrupt the user from the other activity(ies) they are performing. If the user interface is not designed well, this side effect of user-interruptions can have serious, even life-threatening consequences. The user's attention can become dominated by a single task — not because the task demands constant attention, but because the design of the system ignores peoples' cognitive limitations related to distraction and interruption.

Interrupting the user is not a "bad" thing. Instead, interruption is just another kind of HCI. Although interrupting the user is not inherently "bad," it is a complex kind of human-computer interaction. Because semiautonomous systems do not need constant supervision by their human users, these systems enhance

[1] This report is available online from: the author's internet homepage (http://elazar.itd.nrl.navy.mil/staff/mcfarlane/mcfarlane.homepage.html); and the NRL Library internet database (http://infoweb.nrl.navy.mil/htbin/webcat). (Directions for retrieving this report from the NRL Library internet database: (1) click the "Launch NRL Library Catalog (Web Interface)" link; (2) click the "LIBRARY CATALOG" link; (3) click the "AUTHOR" link; (4) set the "library" pulldown menu under "LOOKUP OPTIONS" to "NRL_PUBS"; (5) type in the author's name, and search.)

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peoples' ability to perform multiple tasks at the same time (multitasking). However, there is an inherent conflict between users' multitasking and their semiautonomous computer system's HCI activity of user-interruption. This HCI design problem is still unsolved. Authors have not yet published generalizable methods for designing user interfaces that allow the HCI of user-interruption without producing detrimental side effects.

Motivation

My goal is to construct a unifying definition which has the maximal power to facilitate generalization of research results about interruption across domains. Therefore, I synthesize my unifying definition from the commonalities across the entire set of revealed theoretical constructs of interruption. [2]

1.1 Timeliness of Research

Research should make things better. However, improvements in one area can cause new and dangerous side effects in other areas. This is true of the technology improvements from research in applied AI and multitasking. Applied AI and multitasking are useful, but their introduction has caused an increase in the HCI side effect of user-interruption. For example, the following new computer science technologies inadvertently cause the HCI side effect of user-interruption: intelligent software agents; computer-supported cooperative work; intelligent user interfaces; multitasking; and intelligent decision aids.

Technical improvements have historically resulted in side effects that must themselves be investigated. There are illustrative examples of this trend in noncomputer fields of technology. Transportation is a good example. Traffic at street intersections was not problematic until the invention and mass sale of automobiles. After cars became popular, people had to solve this now-serious side effect of greatly intensified traffic at street intersections. This problem was eventually solved with the invention and installation of traffic lights. The car itself is another good example of technical improvements causing important side effects. Original cars were slow and light. As car technology quickly improved, cars became both faster and heavier. However, an important side-effect emerged — as cars became faster and heavier, the severity of automobile accidents increased dramatically. This life threatening side-effect created a need for the inclusion of safety mechanisms like steel unibody construction, seat belts, shoulder belts, crumple zones, air bags, high seat backs, etc.

Like the street traffic and the automobile, improvements in computers sometimes cause previously inconsequential side effects to grow into important problems. Recent advances in AI and multitasking have caused the HCI of user-interruption to become a critical problem.

There is an excellent example of how adding AI technology to an existing system causes an increase in user-interruptions. This example comes from the "Intelligent Control and Interface Design" (ICID) research project (Ballas et al. 1996; Kushnier et al. 1996) at the Navy Center for Applied Research in Artificial Intelligence (NCARAI). ICID is a dynamically changing research platform for investigating decision-

[2] I disclaim the "truthfulness" of this work. It is not important (or even possible) to have a single "true" definition of a scientific concept. Scientific communities usually entertain several different competing definitions about key concepts. What is important is the relative usefulness of a particular definition in explaining observations and in generating useful theory. I do not claim that this survey reveals any "true" structure or function about human cognition or any "true" theoretical constructs of human interruption. I do not survey any authors who present or validate any truth about the structure and function of human cognition. Instead, they, and I, claim only utility. I survey authors who present theoretical constructs that sometimes contradict. I make no attempt to say who is "right" or "wrong." Instead, I first review these diverse definitions and theoretical constructs of interruption, and then I synthesize a single unifying definition that includes useful properties from several diverse fields but that is also maximally generalizable.

aid tools for Navy commanders in the context of tactical battle management. Over the last 4 years, the ICID research team has repeatedly increased the capability of ICID by introducing additional, new, intelligent decision aids (similar to intelligent agents). First ICID included an intelligent decision aid that gave advice for management of a tactical air battle. Next they added an aid that supports situational awareness by interactively deducing complex relationships between observed man-made objects in the environment. The ICID researchers are currently adding a new, intelligent decision aid that automatically deduces and alerts the user to occurrences of standard enemy attack patterns. The ICID research team has observed that, while each of these additional decision aids provides a useful function, each new, additional aid also places new interactional demands on the user. Each additional intelligent decision aid potentially interrupts and/or distracts the user in new and different ways; and this compounds the HCI problem of user-interruption. The resulting HCI requirements for supporting user-interruption become complicated.

1.2 Apparent Trade-Off Between Speed on a Single Task and Coordinated Performance of Multitasks

New technologies of applied AI and multitasking allow people to do things they could never do before. However, before people can begin enjoying the full benefit of these new technologies, researchers must solve the new side effects. Researchers must discover how to design HCI that accommodates the user's cognitive limitations to avoid the detrimental side effects of interrupting and distracting the user.

System designers have traditionally chosen HCI methods that maximize the speed of getting information into and out of computers. They have employed the assumption that, if the design of a user interface increases the user's efficiency on a single task, then that user will be more productive overall. However, is speed on a single task a good predictor of overall performance of a modern computer system? I say, no, except in unusual circumstances.

I suggest it is possible that a user interface design that facilitates a person's fast performance of a single computer task may be the very same design that hinders their ability to perform multitasks. The design of a user interface for an intelligent software agent system is a good example. This user interface design must address the system's HCI requirement that it interrupt the user. From one perspective, the most efficient way to solve this problem is to use a method of immediately interrupting the user whenever needed — this design should facilitate the user's speedy input or output of information. This design may be superb if the user is performing only one task with one software agent. However, if the user is performing multiple tasks at the same time, this method of interruption may be counterproductive. For a human multitask environment, each computer system must be designed so that it does not monopolize its users and hinder them from performing other tasks. The user interface for an intelligent agent system must not be designed to seize the user's attention away from their other tasks (except in special critical situations, like warning a person of their immanent death, e.g., "There is a coolant leak in the nuclear reactor core!").

There is an old debate in the field of HCI about whether command-based interface designs or direct manipulation interface designs are better. This debate centers around a presumed trade-off between effort and speed. Authors have debated which end of the trade-off is more important — user effort and learning time or maximally efficient task performance. Card et al. (1983) found support for a third possibility — that the presumed trade-off could be sidestepped altogether. They found that, for several kinds of computer systems, a direct manipulation design solution could produce a system that would be both easier to learn and faster for performing tasks than command-based design alternatives.

There is another apparent HCI design trade-off — between speed and multitasking. It would seem that an HCI designer must choose between HCI designs which support users' efficient performance of single tasks and HCI designs which support users' performance of multitasks. Human cognitive limitations

restrict peoples' ability to both perform focused work and maintain awareness of several tasks at the same time. Because of this human cognitive limitation, it would seem that computer system designers must decide to trade-off one kind of support for another. I assert that it is possible to discover a way to sidestep this apparent HCI design trade-off, in much the same way that Card et al. found a way to sidestep the "effort vs speed" HCI design trade-off. It should be possible to design a computer system which will both support users' efficient performance of single task and, at the same time, manage user-interruption in ways necessary for multitasking.

1.3 Need for a Single Unifying Definition of Interruption

To find a way to sidestep the single-task-speed vs multitasking-interruption trade-off, researchers must have theoretical tools and the practical means to apply them. These tools do not exist yet. A general investigation of this problem requires two kinds of theoretical tools. First, researchers need a unifying definition of interruption to allow them to generalize and use the existing results in the literature from disparate fields. Without a unifying definition of interruption, it is impossible to integrate findings from diverse fields. Second, researchers need a taxonomic tool to augment this unifying definition and make it practically applicable. Such a taxonomy of human interruption should facilitate efforts to describe and analyze interruptions.

This report also provides two index tools: one, is an aid for comprehensively identifying relevant fields of current literature and the other is an aid for comprehensively locating theoretical constructs by relevant topic.

In the current literature, authors from different fields of research describe the interruption phenomenon only within the context of their particular domains, without recognizing this phenomenon in other contexts. No author has yet made an attempt to propose a well-crafted general definition to unify research about the interruption phenomenon. Instead, authors describe aspect(s) of interruption within their particular domain: how, when, why interruptions occur, or the observed effects and side effects of interruption. Other authors begin by implying vaguely that interruptions [whatever they are] are inherently "bad" and then propose specific methods for counteracting the implied problem within their particular domain.

1.4 Approach

In this report, I analyze the current literature and identify theoretical constructs relevant to the interruption phenomenon. These identified theoretical constructs comprise a jumbled, incomplete, and sometimes contradictory model of what the current literature tells us about the interruption of people. However, something is better than nothing — even this raw conglomeration of a model can be useful in researching questions about the who-what-where-when-why-and-how of human interruption. (This is also true for the more narrow questions about the HCI for user-interruption.)

I use the results of this analysis to synthesize a unifying definition of interruption, which establishes those theoretical constructs that are most significant and ubiquitous across different fields. The breadth and depth of this analysis and the resulting unified definition's strict simplicity make the theoretical products of this report powerful tools for guiding general research about human interruption.

I categorize all theoretical constructs of interruption by the four things to which they must apply: (P) the people involved in the interruption; (T) the task(s) the person is attempting; (In) the interruption itself; and (C) the working context or environment. My four categories of theoretical constructs reveal the limited scope of my claimed "unifying" definition. I create a definition of interruption that is useful only for people concerned with mediating the interruption of a human as he or she attempts to accomplish task(s) within

some environment. I do not attempt to address the interruption phenomenon for other possible domains. As an extreme example, I do not review literature from organic chemistry about the interruption of chemical reactions. My work will therefore be most useful to researchers working on the problems of interrupting people. I postulate that these four categories are sufficient (within my limited scope) to address all relevant theoretical constructs of the interruption phenomenon.

Authors of current literature have discovered useful theoretical constructs of interruption in each of my four categories. In my *first* category (the people involved in the interruption), authors have discovered particular attributes of a person's cognitive and physical structure that affect their behavior during and after interruption. These attributes represent important structural and behavioral characteristics of a person relevant to their interruption. In my *second* category (the task(s) the person is attempting), authors have identified aspects of tasks that are related to the user's changes in performance during and after interruption. These task attributes represent important qualities of tasks that affect the outcome of interruption. In my *third* category (the interruption itself), authors have discovered qualities of the interruption that affect how the people involved in the interruption behave. These qualities of the interruption represent significant theoretical constructs that are relevant to people's performance during and after interruption. In my *fourth* category (the working context or environment), authors have discovered particular environmental characteristics that affect the outcome of an interruption. These characteristics represent important environmental influences on the interruption phenomenon.

In summary, I survey and analyze the current literature to reveal theoretical constructs of interruption that are likely to be significant and common to all interruption events within the broad scope of this report. Then I use these theoretical constructs to synthesize and propose a unifying definition of the interruption.

1.5 Application of this Unifying Definition of Interruption and its Accompanying Taxonomy

The theoretical tools presented here are useful for investigations of human interruption. They are especially useful for researching user-interruption in HCI. They are a unifying definition of interruption and an accompanying practical taxonomy.

These tools help guide research in the following ways: (1) they help researchers quickly analyze and describe their particular interruption phenomenon along several important and useful dimensions; (2) they aid researchers in finding, generalizing, and applying other people's results from the current literature to their own work; and (3) these theoretical tools make it possible for researchers to contribute to other people's work by increasing their ability to create and publish maximally generalizable research products.

Researchers need to analyze and describe the particular interruption events they investigate. Analysis helps them discover the important structures, processes, and relationships evident in a problem. This knowledge produced from analysis is critical for making informed hypotheses and operationalizing investigations. Description of the problem is also essential for communicating with coworkers about research and as a memory tool for maintaining an overall perspective.

Groups of people from various research domains attempt (and have attempted) to address the problems associated with interrupting people. However, since there is no single unifying definition of interruption, each group invents its own specialized definition of what it means to interrupt people; and this inconsistency of basic definition severely limits the generalizability of results across fields. The unifying definition of interruption presented here is a theoretical tool that can be used to solve this problem by increasing the generalizability of published work across domains.

The general usefulness of the theoretical tools presented here is directly relevant to the breadth and depth of the analysis used to create them. A larger analysis means a greater generalizability. I have tried to maximize the usefulness of this unifying definition by broadening and deepening the analysis portion of this effort to encompass a wide variety of relevant domains. This broad coverage includes many different perspectives and diverse theoretical constructs of interruption regarding people, tasks, interruptions, and contexts. Any omission to from this analysis would decrease the usefulness of the synthesized theoretical tools.[3]

I have created a taxonomy of human interruption to augment the practical usefulness of the unifying definition of interruption presented here. This taxonomy is a tool for describing interruption events. It is useful because of the complexity of the interruption phenomenon. It helps researchers analyze and describe the particular interruption events they are investigating.

I also present two indexes. These are tools for indexing relevant sources of published research relevant to interruption. These tools are useful because there are numerous relevant but diverse fields of research and because of the breadth and length of the analysis of theory contained in this report. The mere ubiquitousness of interruption in human behavior makes comprehensive investigation difficult.

These theoretical tools can be useful for two different kinds of activities: (1) basic research into HCI theory and (2) applied research about user-interruption. The large analysis of theory from diverse fields is the bulk of this report. Each subsection of analysis summarizes useful theoretical constructs of interruption from a distinctly different research perspective. However it is the unifying definition and its associated taxonomy (contained at the end of this report) that make this lengthy report most useful. These theoretical tools, i.e., definition and taxonomy, are useful for doing faster and better research about human interruption.

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[3] Although it is necessary to analyze many diverse fields, I realize that some readers are more interested in useful tools than in a lengthy analysis of relevant theoretical concepts. I invite these readers to skip the background material (although it is also useful), and go to Section 3 on pg 66 on new synthesized tools.

2 ANALYSIS

Aims and Objectives

The aims of this section are to discover, identify, and discuss all published theoretical constructs that are relevant to the interruption of humans. There does not exist a general model of how people are interrupted; and building such a model is beyond the scope of this report. However, this report aims to build the next best thing. This report finds and gathers all the pieces necessary for building such a comprehensive model of human cognition for interruption. These identified pieces, or large pile of theoretical constructs, can be considered to comprise a jumbled, incomplete, and contradictory model in and of itself. This poor conglomeration of a model is still better than anything else available and good enough for the purpose of synthesizing useful theoretical tools. (Note: the taxonomy presented in Section 3 (p. 73) offers some glue and infrastructure for holding this conglomerated model "glomerated.")

After reading this section, readers should understand the several individual theoretical constructs relevant to investigating the interruption of humans, and readers should have formed their own rough, general model of human cognition relevant to interruption.

Overview

The phenomenon of interrupting people is common in many different contexts. However, no single field of research has produced a generalizable model of human interruption. Instead, authors working in different fields of research each address interruption of people only within the limits of their specific domains. These authors publish their works with different definitions of what it means to interrupt people — a different definition of human interruption for each field of research. Therefore, published findings about interruption in the current literature cannot be generalized across different fields of research.

This section examines several different domains of research from the current literature. Analysis proceeds one research domain at a time. This section is organized into subsections by the particular definitions of interruption employed by different fields of research. Within each subsection, this section discusses the relevant theories a of a particular domain of research and identifies and explains the individual theoretical constructs promoted there.

This analysis systematically extracts the relevant theoretical constructs from each domain of research in the current literature. The resulting large list of individual theoretical constructs can be employed as a crude theoretical model. Although this set of individual constructs is not a refined model, it can be used to synthesize powerful and generally useful theoretical tools for investigating the interruption of people.

This section makes a significant contribution by uncovering a large set of theoretical constructs relevant to the investigation of human interruption.

Motivation

A comprehensive model of human interruption is necessary to synthesize generally useful theoretical tools for the investigation of human interruption. No such model exists. This section creates a large set of individual theoretical constructs to serve as a rough proxy for a comprehensive model.

2.1 Colloquial Meaning

Domain Specific Definition of Interruption: a word of the English language.

It is useful to begin with the etymological perspective of the meaning and usage of the word, "interrupt," in the English language. I quote an authoritative popular standard dictionary for a definition of interruption. *Webster's Encyclopedic Unabridged Dictionary of the English Language* is a widely respected standard source for definitions of English words.

> **interrupt,** *v.t.* 1. to cause or make a break in the continuity or uniformity of (a course, process, condition, etc.). 2. to break off or cause to cease, as in the middle of something: *He interrupted his work to answer the bell.* 3. to stop (a person) in the midst of doing or saying something, esp. by an interjected remark: *May I interrupt you to comment on that last remark?* —*v.i.* 4. to cause a break or discontinuance; interfere with action or speech, esp. by interjecting a remark: *Please don't interrupt.* [ME *interrupte(n)* < L *interrupt(us)* broken apart (ptp. of *interrumpere*), equiv. to *inter-* INTER- + *ruptus* broken; see RUPTURE] —interruptedly, *adv.* —interruptedness, *n.* —interruptible, *adj.* —interruptive, *adj.*
>
> —Syn. 1, 3. intermit. INTERRUPT, DISCONTINUE, SUSPEND imply breaking off something temporarily or permanently. Interrupt may have either meaning: *to interrupt a meeting.* To DISCONTINUE is to stop or leave off, often permanently: *to discontinue a building program.* To SUSPEND is to break off relations, operations, proceedings, privileges, etc., for a longer or shorter period, usually intending to resume at a stated time: *to suspend operations during a strike.* —Ant. 1, 2. continue (Random House 1989, p. 744).
>
> **interruption,** *n.* 1. the act or an instance of interrupting or the state of being interrupted. 2. something that interrupts. 3. cessation; intermission. [ME *interrupcio(u)n* < L *interruption-* (s. of *interruptio*)] (Random House 1989, p. 744).

These definitions and usage quotation examples help us understand what authors usually mean when they use the word interruption. I propose that this definition is useful because it describes what most English-speaking people believe to be common and obvious about the phenomenon of interruption. I distill from Webster's definition six purportedly common or obvious theoretical constructs about the interruption of people's activities (including interruption of their speech). I use a metaphor of water flowing through a ditch to illustrate the theoretical constructs of interruption, which I identify from the preceding definition. In this metaphor, interruption is what happens when the ditch is blocked and the water stops.

THEORETICAL CONSTRUCT(S) about people (Random House 1989, p. 744):

P1. Human activities are continuous, fluid processes [like flowing water].

P2. Human activities have coherence over time [like the surface tension of water].

P3. People's actions are interruptible [in the same way that water can be divided].

THEORETICAL CONSTRUCT(S) about interruption (Random House 1989, p. 744):

In1. An interruption is something that breaks the coherence of an activity and blocks its further flow (like dropping (interjecting) a large rock in an irrigation ditch).

THEORETICAL CONSTRUCT(S) about people (Random House 1989, p. 744):

P4. People can resume activities that have been interrupted once the interruption is removed (like removing the rock).

P5. People often use conventional protocols for interrupting each other's speech, for example, "May I interrupt you to comment on that last remark?" There are also protocols for interrupting all other kinds of human activities. (Also, I can use my metaphor of blocking an irrigation ditch with a rock to illustrate people's use of protocols. If I just drop the rock in the ditch, I will splash water and mud all over myself. Instead, I must use the protocol of slowly lowering the rock into place.)

2.2 Multitasking in HCI

Domain Specific Definition of Interruption: an unanticipated request for task switching during multitasking.

Tsukada et al. (1994) present a practical discussion of how people get work done in computer-supported cooperative work (CSCW) office environments where a person is responsible for advancing several projects at the same time. It is unusual for a person to be engaged in only a single activity from start to finish to the exclusion of all other tasks. This behavior in which a person accomplishes two or more tasks within the same time period is called multitasking. Researchers in this field define interruptions as unanticipated requests for switching between different tasks during multitasking. (See also (Preece et al. 1994, p. 105).)

Tsukada et al. does not specifically address the interruption of a worker, however the authors make a useful distinction between a person's internal and external actions. Tsukada et al. says that people can multitask because they internally concern themselves with all their multiple tasks at once, in parallel, but externally act on only one task at a time. People multitask by frequently alternating their external efforts between each of their multiple tasks. The result is that a person can accomplish multiple tasks concurrently, as Fig. 1 shows.

Tsukada et al. defines theoretical constructs about the cognitive and physical structure of the people involved in the interruption and about the requirements of tasks. These theoretical constructs are relevant to the interruption phenomenon.

THEORETICAL CONSTRUCT(S) about people (Tsukada et al. 1994):

P6. There is a useful distinction between people's internal efforts and their external efforts on tasks. People's internal and external efforts are related, but there is also some amount of independence between these two kinds of efforts. People's external efforts (observable behaviors) are dictated by their internal efforts (cognition), but not all of people's internal efforts become expressed as external efforts.

P7. People can exert external effort on only one task at a time.

P8. People can switch their external effort from one task to another; i.e., a person can stop their external efforts on one task before it is completed and begin or resume their external efforts on another task.

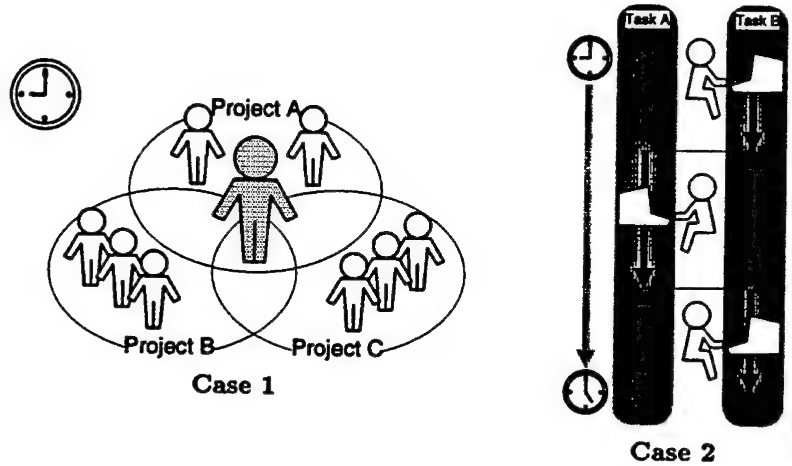

Fig. 1 — The left-hand diagram illustrates the parallel nature of a worker's internal effort in multitasking. The right-hand diagram illustrates the serial time-sharing nature of a worker's external efforts in multitasking. Reproduced from Tsukada et al. 1994, p. 359.

P9. People can exert internal effort on multiple tasks at the same time — in parallel.

THEORETICAL CONSTRUCT(S) about tasks (Tsukada et al. 1994):

T1. It is not required that a task be accomplished all at once, but a task can be performed through the accumulation of many independent, noncontiguous efforts.

Card, Moran, and Newell (Card et al. 1983) present some of these same theoretical constructs (11 years before Tsukada et al.) in their remarkable book, *The Psychology of Human-Computer Interaction*. Card et al. only model a person performing one task at a time. However, I think their work is fundamental to this discussion of multitasking and user-interruption. Card et al. present a model of the structure and function of human cognition relevant to task execution. They call their model "The Model Human Processor" (Card et al. 1983, p. 24), as seen in Fig. 2.

The Model Human Processor depicts human cognition with three parallel processors. These separate processes model human cognition in a way that allows a theoretical person to perform three kinds of internal processing simultaneously. This model also limits a theoretical person to one external action at a time, because only one processor, the Motor Processor, controls external actions. Card et al. say, "the cognitive system is fundamentally parallel in its recognizing phase and fundamentally serial in its action phase. Thus the cognitive system can be aware of many things but cannot do more than one deliberate thing at a time" (Card et al. 1983, p. 42).[1]

Card et al. discretize actions at ~ 70 msec units. Actions are discretizable because the Motor Processor of the Model Human Processor is cyclical. This cyclic behavior of the Motor Processor divides its output into discrete units. Card et al. say that the cycle time of the Motor Processor is 70[30-100] msec (Card et

[1] Compare this idea of parallel cognition and serial action to the theoretical constructs of interruption P7 (p. 9), and P9 (p. 10). This idea or theoretical construct is not unique to the Model Human Processor. In fact, several of the theoretical constructs that I discuss in Section 2 have sibling constructs in different domains of research. One contribution of this report is to find and gather these siblings together for examination so that the gereralizable part of the idea can be extracted.

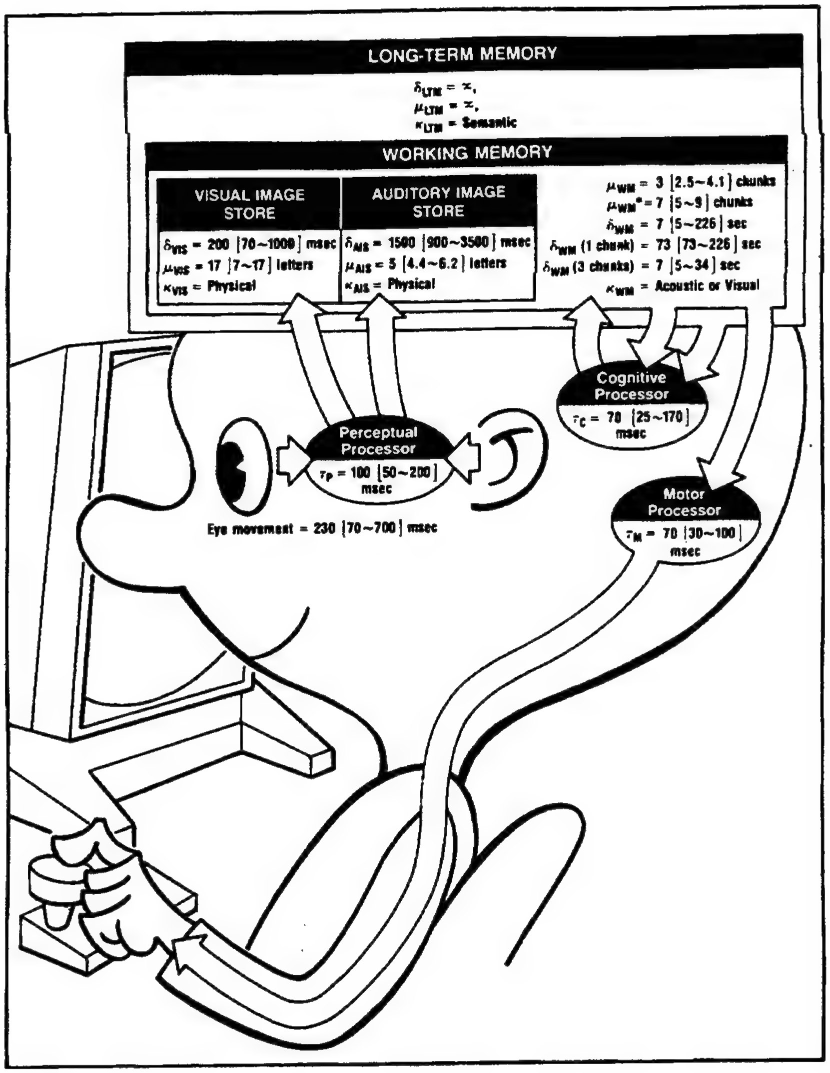

Fig. 2 — "The Model Human Processor — memories and processors." Reproduced from (Card et al. 1983, p. 26).

al. 1983, p. 34). (This means the typical value is 70 msec and that the possible range is from 30 msec to 100 msec.)[2] The authors say that people perform all their motor behaviors merely with long chains of tiny 70 msec actions. The Model Human Processor allows researchers to quantify larger actions as sums of the different kinds of tiny 70 msec actions that comprise them, as seen in Fig. 3.

Figure 3 shows the results of one subject's moving a pen back and forth between two lines as fast as possible in 5 seconds. The subject made 68 lines in 5 seconds — thus 5000 msec divided by 68 actions equals about 74 msec per action. Card et al. say this observed behavior is illustrative, informal support for

[2] Card et al. choose the specific numbers for their Model Human Processor capabilities from empirical studies in contemporary literature. For example, they set the cycle time of the Motor Processor at 70[30-100] msec. Card et al. describe the several other papers they used to find an average estimate for the Motor Processor speed at 70 msec, and the published extreme observations at 30 msec and 100 msec.

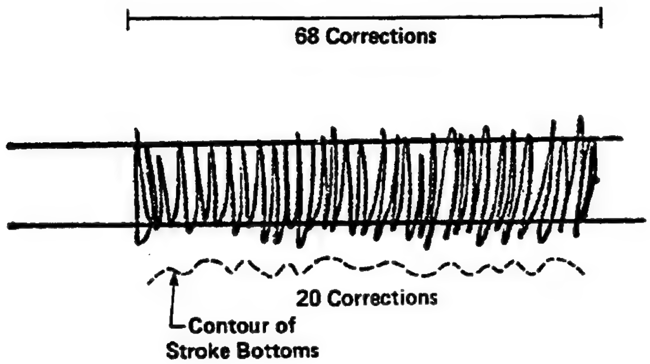

Fig. 3 — An illustrative example task from Card et al. People's observed behavior informally validates the Model Human Processor's cycle rate for the Motor Processor. Reproduced from (Card et al. 1983, p. 35).

the speed of their Model Human Processor's Motor Processor cycle rate. The Model Human Processor allows us to say that this squiggly line drawn by a person in 5 seconds is actually the result of a chain of 68 tiny discrete actions (Card et al. 1983, p. 35).[3]

THEORETICAL CONSTRUCT(S) about people (Card et al. 1983):

P10. People can perform actions in parallel along three dimensions — perceptual, cognitive and motor, but within each of these three dimensions, people must perform actions sequentially.

P11. People discretize tasks cognitively. People hierarchically decompose large tasks into smaller tasks, and they continue this decomposition until subtasks are reduced into indivisible units of work. The size of these basic units of work is related to the cycle time of human's three cognitive processors.

P12. People perform large actions by executing chains of smaller discrete actions.

Card et al. also provide a modeling and analysis tool that supports the theoretical construct of interruption T1 (p. 10). They apply some of their ideas from the Model Human Processor to create a family of practical analysis tools called the GOMS (Goals, Operators, Methods and Selection rules) Models. The GOMS Models rely heavily on the idea that human actions are discretizable. GOMS can be employed to model how a person would perform a given task. The task is analyzed hierarchically into the subtasks that comprise it ("Goals"). These subtasks are modeled with chains ("Methods") of basic operations ("Operators") that must be performed to accomplish them. The "Selection rules" are productions to simulate which chain a person would choose among alternatives to complete a subtask depending on the context. GOMS Models can be used to analyze tasks and make a priori, quantitative predictions of human performance.

[3] This observed 74 msec per action illustrates the cycle time of the Model Person's Motor Processor in isolation. The observed correction behaviors can be modeled with the Model Person with chains of behaviors in which the total time is the sum of the cycle rate of each processor employed. Each correction behavior represents a chain of one cycle each for the Model Person's Perceptual Processor, Cognitive Processor, and its Motor Processor. Twenty corrections in 5 seconds means 250 msec per corrective chain of behavior.

Card et al. does not support our need to model multitasking or the interruption of the user by unanticipated requests for task switching. They have only intended the Model Human Processor and the GOMS Models to be used to model and analyze the event of a single user performing a single task, uninterrupted. The three processors of the Model Human Processor are intended only to model parallel cognition on a single task. The GOMS Models have no way of suspending the execution of one task and resuming another. I have included Card et al., however, because the Model Human Processor and GOMS Models represent early contributions of theoretical constructs about people and tasks that are relevant to the interruption phenomenon. They proffer the ideas that human actions can be discretized and that arbitrary chains of atomic actions can be composed to model complex actions. They also promote the idea that subtasks can be accomplished by dynamically selected chains of atomic operations.

More recently, the GOMS Models have been extended to model aspects of multitasking. John and Gray (1995) present a modified version of GOMS called CPM-GOMS. CPM-GOMS is Critical Path Method-GOMS (CPM also can stand for Cognitive, Perceptual, and Motor operations). CPM-GOMS further applies the structure of the Card et al. Model Human Processor by specifically employing the idea of three separate processors (Cognitive, Perceptual, and Motor). CPM-GOMS can be used to model human performance on tasks by first modeling subtasks with short chains of operations. These small chains must then be linked in sequence to model human performance on larger tasks.

These chains are executed by scheduling their respective operators on three separate time tracks — one per processor. Each operator needs to be scheduled on an appropriate processor (Cognitive, Perceptual, or Motor). Therefore, a small chain of operators that models a single subtask may have operators scheduled on each of the three processor schedules. The result of CPM-GOMS modeling is a three-part parallel schedule for the three processors of the model. The schedule can be traced in parallel to estimate the time required for a person to perform the task.

However, the real improvement of the CPM-GOMS over the original GOMS comes from using the added flexibility of its improved control structure. After finishing the model of the entire task as a long succession of small chains, a researcher can begin using the flexibility of CPM-GOMS to improve the accuracy of the model. CPM-GOMS allows a researcher to collapse the final chain by interleaving the smaller chains that comprise it. As long as temporal dependencies are preserved, the operators from different subtasks can be interleaved within the processor schedule tracks. So, for example, if the researcher notices that at one point in its schedule, the Cognitive Processor is idle, waiting for the result of the Motor Processor, the researcher can collapse the Cognitive Processor's schedule so that it can work on an operator for a successive subtask while waiting. Later, when the Motor Processor has finished, the Cognitive Processor can resume executing the operators for the subtask it had begun.

John and Gray have implemented fundamental aspects of the structure of human cognition in CPM-GOMS. They apply the idea that people can do things while they wait for themselves to finish doing other things. This sounds strange, but since people are processing information in parallel on three processors (the Card et al. Model Human Processor — Cognitive, Perceptual, and Motor), they can do three things at a time. So if a person is only using one of their three processors to perform some task, they can use their two idle processors to do other tasks while they wait for themselves.

THEORETICAL CONSTRUCT(S) about people (John and Gray 1995):

P13. People can intermix their actions for different tasks because of their ability to act in parallel along three dimensions (cognitive, perceptual, and motor). While they wait for themselves to finish some basic processing along a single dimension, they can perform work on other, possibly unrelated, tasks within each of their other two processing dimensions.

P14. People can switch their actions between different tasks quickly and effortlessly.

Preece et al. (1994) say that although people are able to multitask, they have cognitive limitations that make them vulnerable to distraction. "While most people show great flexibility in coping with multitasking, they are also prone to distraction. On returning to a suspended activity, it is possible for them to have forgotten where they were in the activity. As a result they may not restart from where they left off but will recommence at a different point of entry. For example, pilots may think they have completed part of a procedure (such as a checklist) but in fact they have not done so. [See story on p. E-1 about the airplane pilots and an uncompleted checklist.] Alternatively, they may forget that they have already done something and repeat it. This most frequently occurs for routine procedures where knowledge for carrying out the various tasks has become largely automated. An everyday analogy is forgetting to salt the potatoes or adding the salt twice, if our routine procedures when cooking are interrupted by having to answer the phone" (Preece et al. 1994, p. 105).

Preece says that distraction affects people's memories. Distraction diverts their attention and causes them to forget what they were doing. The combination of distraction and interruption can have especially bad consequences. The occurrence of an interruption is a circumstance when it is particularly important for a person to remember what they had been doing on the interrupted task. Since distraction affects memory, it can cause people to make serious memory errors when resuming the interrupted activity.

Webster's Encyclopedic Unabridged Dictionary of the English Language presents a useful colloquial definition of "*distraction*." I quote it here:

> **distract** *v.t.* 1. to draw away or divert, as the mind or attention: *The music distracted him from his work.* 2. to divide (the mind, attention, etc.) between objects. 3. to disturb or trouble greatly in mind: *Grief distracted him.* 4. to amuse; entertain; provide a pleasant diversion for: *I'm bored with bridge, but golf still distracts me.* 5. to separate or divide by dissension or strife. —*adj.* 6. Obs. distracted. [< L *distract*(*us*) (ptp. of *distrahere* to draw apart), equiv. to *dis-* DIS- + *tract-* (perf. s. of *trahere* to draw) + *-tus* ptp. suffix] —distracter, *n.* —distractibility, *n.* —distractible, *adj.* —distractingly, *adv.* (Random House 1989, p. 417).
>
> **distraction** *n.* 1. the act of distracting. 2. the state of being distracted. 3. mental distress or derangement: *That child will drive me to distraction.* 4. that which distracts, divides the attention, or prevents concentration: *The distractions of the city hinder my studies.* 5. that which amuses, entertains, or diverts; amusement; entertainment: *Fishing is his major distraction.* 6. division or disorder caused by dissension; tumult. [< L *distraction-* (s. of *distractio*) separation (Random House 1989, p. 417).

THEORETICAL CONSTRUCT(S) about people (Preece et al. 1994):

P15. There exist certain stimuli, called distracters, that can affect people's attention and working memory outside of their conscious control and awareness.

THEORETICAL CONSTRUCT(S) about tasks (Preece et al. 1994):

T2. There exist some nonwork activities that can distract people from work tasks.

THEORETICAL CONSTRUCT(S) about interruption (Preece et al. 1994):

In2. There is an interaction effect between distraction and interruption. When a distraction is associated with an interruption, people become prone to make serious memory errors when attempting to resume interrupted tasks.

2.3 Multitasking in Linguistics

Domain Specific Definition of Interruption: an unanticipated request for topic switching during asynchronous parallelistic human-computer interaction.[4]

Edmondson (1989) in his paper titled "Asynchronous Parallelism in Human Behaviour: A Cognitive Science Perspective on Human-Computer Interaction," explains how a particular linguistic theory can be useful in HCI research of multitasking. He proposes that a prominent theory of linguistics about phonology, called autosegmental or nonlinear phonology, can provide useful concepts and formalism for HCI research about multitasking environments.

Edmondson says that people exhibit the readily identifiable and common behavior of "asynchronous parallelism." He says that this behavior can be observed in many different kinds of human activities, including human-human interaction (the domain of linguistics) and human-computer interaction (HCI). Edmondson says that asynchronous parallelism describes a human behavior in which a person does several things at once (parallelism), but they accomplish this by working on only one thing at a time while interleaving the execution of all the different activities (asynchronism). (Other popular terms that refer to people's asynchronous parallelistic behavior are nonlinear, plurilinear, or interleaved behavior.)

Edmondson does not directly address the interruption of the user. However, he does show how tools for addressing asynchronous parallelism can be generalized across domains. He postulates that human asynchronous parallelistic behavior will have similar cognitive requirements and limitations across different domains. This premise has two important implications: (1) the tool Edmondson proposes, nonlinear phonology, can be useful for addressing some issues of HCI in supporting people's multitasking, and (2) other tools created for other domains involving people's asynchronous parallelism (some of which directly address human interruption) can be generalized to the HCI domain.

THEORETICAL CONSTRUCT(S) about people (Edmondson 1989):

P16. Asynchronous parallelism is a common and easily observed behavior exhibited by people in many and widely varied activities, including human-human interaction and human-computer interaction (see Theoretical Constructs P7 (p. 9), P8 (p. 9), and T1 (p. 10)).

Edmondson reports that linguist authors have researched asynchronous parallelism in people's language use and have published useful theoretical concepts and formalisms in the theory of nonlinear phonology. Edmondson says that HCI researchers can adopt and apply these products of linguistic theory

[4] This definition is similar to the preceding definition regarding multitasking, however it comes from a field with different goals and theoretical concepts.

to help them research human-computer interaction in domains where people exhibit asynchronous parallelism, e.g., the HCI of systems that support multitasking. The concepts proposed by these linguist authors are useful here. The formalism, however, is not useful in our attempt to define interruption.

People exhibit asynchronous parallelism in their human-human interaction. This behavior is possible because of the particular structure and function of human cognition. Edmondson's proposed linguistics implies several theoretical constructs of human cognition. I summarize the implied theoretical constructs here. People's linguistic abilities are provided by six general theoretical constructs of cognition:

(1) People maintain and operate discrete units of linguistic expression at several levels of abstraction,
(2) People cognitively prepare linguistic expressions of meaning (at each level of abstraction) as sequences of concatenated or interleaved units of linguistic expression,
(3) People physically express meaning by acting out, one at a time in sequence, each discrete linguistic expression from their cognitive plan,
(4) People self-monitor the success and appropriateness of their linguistic expressions while they are making them,
(5) People use the information from their self-monitoring behavior to dynamically modify and change their cognitively prepared sequence of linguistic expressions as they continue to execute each discrete expression, and
(6) People exhibit asynchronous parallelism in expressing meaning to other people — they cognitively prepare in parallel but express in sequence (asynchronously).

Card et al. propose the concept that people accomplish physical actions by sequentially performing long strings of discrete movements (see Fig. 3 (p. 12) and Theoretical Constructs P10 (p. 12), P11 (p. 12), and P12 (p. 12)) (Card et al. 1983). Edmondson is proposing this same idea for people's linguistic expressions. For example, people maintain and operate a set of discrete phonemes (a low level of verbal abstraction). When people want to convey meaning to others, they cognitively prepare (in parallel) a sequential list of phonemes and then sequentially speak each phoneme in the list (asynchronously). Edmondson says this same method of asynchronous parallelism is employed at many different levels of linguistic abstraction, e.g., phonemic, morphemic, syntactic, semantic, and pragmatic (rhetorical).

People are not computers doing batch processing on the expression of a list of linguistic units. Instead, people continually monitor the success and appropriateness of their own linguistic expressions. People self-monitor. People's interactivity is not suspended when they are in the process of expressing a sequential list of linguistic units. They can watch their own interactive progress and revise and rework their cognitive composition of planned linguistic actions when needed.

This ability to self-monitor and dynamically replan allows a person to accept interruptions while they are in the very act (in flagrante delicto) of expressing a sequence of linguistic units. For example, if they begin speaking a word and then receive a request for interruption, they can immediately stop speaking that word (without finishing it) and directly begin a totally new sequence of linguistic units. For example, I am at my home talking to Robert (my brother) about which kind of paper he should use to print his résumé. Suddenly, I notice that Kate (my 2-year-old daughter) is about to draw on herself with a marker. I can interrupt myself instantly — I do not even have to finish the word I am currently speaking to Robert. [Quote] "I think this other paper is mo/Kate, no! Markers are not for skin."

In summary, people's asynchronous parallelism is supported by a combination of the following cognitive theoretical constructs: discrete operators; parallel cognitive planning; sequential physical action; continuous monitoring of self and environment; and dynamic cognitive replanning.

Why is asynchronous parallelism so ubiquitous in human behavior? The theory of natural selection provides a useful answer. Our progenitors who could not behave with asynchronous parallelism did not tend to survive. For example, a group of people are standing in the open and talking to each other. Suddenly a pride of lions rushes out of the tall grass nearby. Those people who can behave with asynchronous parallelism IMMEDIATELY interrupt whatever they are saying and RUN. Those other people who cannot behave with asynchronous parallelism do not start running immediately, but instead must stand and finish what they were saying before being interrupted. These stalwart talkers ... tended not to reproduce.

THEORETICAL CONSTRUCT(S) about people (Edmondson 1989):

P17. People maintain and operate discrete units of linguistic expression at several levels of abstraction, e.g., phonemic, morphemic, syntactic, semantic, and pragmatic.

P18. People cognitively prepare linguistic expressions (at each level of abstraction) as sequences of concatenated or interleaved units of linguistic expression.

P19. People physically express their cognitive plan for linguistic interaction by expressing linguistic units one at a time, in sequence.

P20. People monitor themselves and their environment while they are making linguistic expressions.

P21. People use the information from their self-monitoring and environmental-monitoring to dynamically modify and change their cognitively prepared sequence of linguistic expressions as they continue to execute sequentially ordered discrete expressions.

P22. People exhibit asynchronous parallelism — they cognitively prepare in parallel but physically express in sequence (asynchronously).

P23. People can successfully interact with each other (giving and receiving meaning) in an asynchronous parallelistic way. People can understand another person when that person physically expresses, one discrete unit at a time, a sequence of cognitively planned linguistic units.

Edmondson says that asynchronous parallelism in linguistics explains why the inclusion of one linguistic unit in a planned sequence can affect the expression of other linguistic units close by. For example, "Consider the word 'construe' as it is often pronounced by native speakers of English. The second syllable is frequently articulated with lip-rounding throughout, although the lip-rounding is only required as a feature of the vowel. What is happening is that the specification of lip-rounding is spreading back to influence the articulation of the syllable initial consonants (backward assimilation of rounding to the consonant cluster)" (Edmondson 1989, p. 6). Edmondson says that this type of behavior is evidence of people's parallel cognitive planning before their sequential physical expression of linguistic units — asynchronous parallelism. If the linguistic units were cognitively planned sequentially instead of in parallel, then planning one linguistic unit would not influence the specification of preceding linguistic units.

2.4 Multitasking in Situational Awareness

Domain Specific Definition of Interruption: an event that threatens the delicate balance between situational awareness and focused activity, i.e., the reception of unpredictable new data.

Situational awareness is the product of deliberate divided attention. Some authors report research in domains where human situational awareness is critical to successful performance of person-machine systems. One good example is the person-machine system of a cockpit of a commercial aircraft. A pilot has several tasks to perform in concert while at the same time keeping an awareness of the current state of the plane and its outside environment. The pilot must infer the current situation from the information presented by over 400 separate gauges and instruments (Adams and Pew 1990). Situational awareness is essential because a pilot must make decisions that are context sensitive — the correct decision depends on the current state of the airplane.

The balance between situational awareness and focused activity is delicate because of peoples' cognitive limitations. Adams and Pew emphasize the fragility of this balance for aircraft pilots, "an **interruption**, an oversight, a hasty inference, of a decision based on incomplete knowledge or information: under conditions of heavy workload or tight temporal pressure — any crew is vulnerable to each — could mean disaster" (Adams and Pew 1990, p. 519).

A person who has invested the effort to construct and maintain situational awareness has the advantage of already possessing the critical information in their heads when they are called upon to make important decisions. Situational awareness is indispensable in time-critical tasks. Flying an airplane is such a task. An airplane pilot sometimes must make emergency split-second decisions. In these emergency situations, a pilot does not have time to reconstruct knowledge of the current state of the airplane and its environment. This situational awareness cannot be reconstructed when needed in emergencies because it requires too much time— the pilot must read the 400+ gauges and make the necessary inferences to acquire awareness of the situation. It is dangerous for a pilot to allow themself to become interrupted or distracted from their responsibility to construct and maintain situational awareness. When an emergency occurs, the pilot either has the essential situational awareness or not. If yes, then they are ready to make good decisions. If no, then they are ready to make bad decisions.

There are several sobering examples of the possible costs of failure of aircraft pilots to maintain situational awareness. A commercial aircraft crashed in 1972 killing 99 passengers and crew members because none of the crew was aware of the airplane's altitude. In fact, none of the crew was even aware that no one was flying the plane. All of the crew members had become totally focused on solving the problem of a burned-out light bulb in the system that indicates the status of the landing gear. All three crew members were so focused on this minor problem that no one noticed that the autopilot had become disengaged. While they were working on the light bulb problem, the airplane gradually drifted down and crashed in the Florida Everglades. As the airplane gradually descended, an air traffic controller noticed on his radar screen that the aircraft was losing altitude and called the crew on the radio and asked, "how are things comin' along out there?" Because the crew was focused on the light bulb problem they probably assumed that the air traffic controller was inquiring about that, and they responded that everything was all right (Foushee and Helmreich 1988, pp. 194-195; National Transportation Safety Board 1972).[5]

The light bulb example is not unique. A commercial aircraft crashed in 1978 because the crew failed to maintain situational awareness, also because of a burned-out light bulb. The crew was not able to confirm

[5] There is a good source of literature about peoples' cognitive vulnerability to becoming fixated on one topic to the exclusion of others. See references to the Einstellung phenomenon or psychic blindness, e.g., Lane and Jensen 1993.

that the landing gear was down and locked because of a burned-out light bulb, so they prolonged landing the plane while they tried to solve the problem. The captain would not attend to the fact that the plane's fuel was getting dangerously low, and the plane ran out of fuel and crashed several miles from the Portland, Oregon airport (Foushee and Helmreich 1988, pp. 194-195; National Transportation Safety Board 1979).

The stories of airplane accidents attest to the fact that maintenance of situational awareness is very difficult for people. This observed difficulty suggests something about human cognition. Shneiderman (1992, p. 84) comments on this human weakness in his summary of the relative capabilities of humans and current machines. He says that machines are better than people at monitoring prespecified, especially infrequent events, and that people are better than machines at sensing unusual and unexpected events. These theoretical constructs of human cognition often result in people being easily distracted or interrupted from monitoring tasks they are attempting, i.e., people are predisposed to fail at situation awareness.

THEORETICAL CONSTRUCT(S) about people (Shneiderman 1992):

P24. People are not proficient at monitoring events; instead, they are very sensitive to detecting unusual and unexpected events.

Adams and Pew (1990) have written an excellent paper in which they define and review the aspects of human cognition that are relevant to situational awareness in the person-machine system that is a commercial aircraft cockpit. In this paper titled, "Situational Awareness in the Commercial Aircraft Cockpit: A Cognitive Perspective," Adams and Pew say why interruptions are disruptive to the task of situational awareness. "To notice the occurrence of an event in any useful way, the pilot must immediately **interrupt** ongoing activities, at least to evaluate its significance, and establish the priority of its response implications. Resumption of the **interrupted** task must require thoughtful review of its status and may require repetition or reinitiation of one or more of its procedural components. Thus, the very reception of unanticipated data must always introduce an additional and disruptive element of workload. The design implications, especially for time-critical systems, should not be ignored" (Adams and Pew 1990, p. 523).

Adams and Pew detail the relevant task requirements of piloting an airplane. The combination of these requirements describes a task that is especially vulnerable to interruption. We can learn about the interruption phenomenon from a discussion of why this task is difficult. Adams and Pew (1990, p. 520) present four categories of task requirements: (1) there are several tasks that must be performed in concert, each demanding focused attention; (2) each of these several tasks can be both knowledge intensive and procedurally complex; (3) the demands of each of these several tasks are interleaved in time with the demands of other tasks in no predictable order (this leads to situations where "the urgency of executing one or more tasks is liable to peak at the very moment when information triggering, enabling, or urging completion of others is arriving"); and (4) the relevance of each piece of available information is not conveyed by its source or presentation context.

THEORETICAL CONSTRUCT(S) about tasks (Adams and Pew 1990):

T3. Multitasks combining the following requirements are especially vulnerable to failure due to interruption: (1) several tasks simultaneously require the person's focused attention; (2) each of several tasks requires extensive cognitive memory and processing resources of the person; (3) the operations of the tasks must be performed in an unpredictably interleaved order; and (4) the relevance of each piece of available information is not apparent.

Adams and Pew present theoretical constructs of human cognition that are useful here. They say that the constructivist approach to perception is most useful in explaining why it is difficult for people to maintain situational awareness while performing other tasks. According to the constructivist approach, people make sense of new information by employing their own memories to tell themselves what they are seeing. In other words, people do not directly see the world as the images that fall on their eyes; instead they look out at the world through the amazing lens of their memories. The information people receive is usually incomplete and fraught with error and noise. People use their memories to fill in the gaps and allow themselves to make sense of their environments (Preece et al. 1994, section 4.1). Adams and Pew contend that when people maintain situation awareness, they compete with themselves for the cognitive resources they need to constructively perceive incoming information. People are at the same time trying to use these same memory resources to accomplish other tasks.

THEORETICAL CONSTRUCT(S) about people (Adams and Pew 1990):

P25. People must tap their cognitive memory resources when maintaining situational awareness because of their constructivist method of interpreting incoming information. This need for resources causes internal competition between tasks, because each task requires the same cognitive resources.

Adams and Pew say that the structure of human long-term memory has several useful implications for explaining the problems associated with situational awareness. They adopt a connectionist model of memory. This theory says human memories represent information as networks of basic theoretical constructs or concepts and links between them. In other words, each piece of information is represented with the set of its component parts, together with their relationships to each other. The structure of information is preserved by the interconnections in these networks, and the details are preserved by the primitive units of memory. Adams and Pew (1990, p. 521) say that the three most useful aspects of this theory of memory are: (1) the primitive units of memory are not duplicated and are relatively small in number (this means that all memories are just hierarchies of networks of links to the same basic set of primitive units); (2) memories function not only as records of information but also as the medium of perception and interpretation for new experiences (constructivist perception); and (3) the salience of memories increases with the frequency of their use, and since different memories share the same basic set of primitive units, the use of one memory affects the salience of other similar memories.

This connectionist theory of memory is useful in explaining why situational awareness allows pilots to make good decisions during emergencies. While the pilot is constructing and maintaining situational awareness, they are affecting the salience of other memories they have that are related to the particularities of the current situation. This explains why, when emergency strikes, the pilot is able to remember specific information very quickly that will help to solve a particular emergency. The memories of related background information, contingencies, exceptions, and conditional responses have been made more salient because of the frequency of activation of common memory primitives with the specific situation (Adams and Pew 1990, p. 521).

Connectionist theory can also be used to explain why experts are better than novices at both making good emergency decisions and maintaining situational awareness. An expert, by definition, has a much broader repertoire of relevant memories to help with constructivist perception than a novice. The expert uses this more capable and more efficient perception to maintain situational awareness better and more easily than a novice. A by-product of constructivist perception is that other memories that have common memory primitives become more salient. Therefore, memories the expert uses to construct perception become more salient because of this use. When an emergency occurs, the expert has many relevant memories easily available (salient); the novice has many fewer. This accessibility of relevant memories (the

causes of similar emergencies and alternative viable solutions) allows an expert to make better emergency decisions than a novice.

THEORETICAL CONSTRUCT(S) about people (Adams and Pew 1990):

P26. People have connectionist long term memories — each piece of information is represented as a hierarchical collection of its component parts, together with a network that represents the interrelationships of the parts to each other. This memory structure has three characteristic properties: (1) the primitive units of memory are not duplicated and are relatively small in number; (2) memories are used to both store information and as a medium for perception (people have constructivist perception); and (3) the salience of memories increases with the frequency of activation of their constituent primitive memory units.

P27. While people use their memories to constructivistly create and maintain a situational awareness, they affect the salience of all their memories that are somehow related to the particularities of the current situation. This increased salience of related memories prepared during situational awareness efforts gives people fast and ready access to relevant information in unexpected emergencies.

Many classical theories of human memory propose two kinds of memory: short-term memory (working memory) and long-term memory. Classical theory of human cognition says that short-term memory is limited to seven plus or minus two items at a time (Miller 1956). This limitation seems to conflict with a connectionist theory that portrays human memory as being capable of sustaining many, possibly complex, memories active at the same time. Adams and Pew address this apparent weakness in connectionist theory. They adopt a theory of human memory that introduces structures which are useful for explaining human cognitive limitations within a connectionist framework.

Adams and Pew support a theory by Sanford and Garrod (1981) that says there are four different kinds of memory: two kinds of active memory (explicit focus and implicit focus), and two kinds of latent (currently inactive) memory (long-term episodic and long-term semantic). Sanford and Garrod say that each of these different kinds of memory has a different structure and function and that these differences in structure are useful in explaining human memory behavior and limitations. They have limited the scope of this theory to defining structures that influence the way human memories are retrieved. (Other aspects of memory are not addressed by this theory, e.g., formation of memories, use of memories in constructivist perception, and selection between competing memories.) Sanford and Garrod demonstrate the usefulness of this theory of memory structure in their domain of text comprehension. Therefore, if we can generalize from the text comprehension domain, we can use this theory to explain how memories are made more or less salient. This is a useful tool for talking about the interruption phenomenon, because we can use it to explain memory problems related to interruption events.

Explicit focus memory is active memory that has been the subject of classical memory studies to measure "short-term memory." The explicit focus consists of a tightly limited number of tokens (or pointers), which refer to larger knowledge structures in long-term memory. So, explicit focus memory is like an index, and its tokens are the references listed there. The salience of tokens in this index are maintained dynamically. (The degree of salience determines how easily a memory can be recalled and used.) The salience of a token is determined by its recency of use and by its relevance to the current context (relevancy to the current context can be explained by a discussion of constructivist perception). Implicit focus memory is composed of the large, possibly complex, active memory structures referred to by the tokens in the explicit focus memory.

Classical studies of short-term memory suggest that there are only seven plus or minus two tokens in short-term memory (Miller 1956), however Sanford and Garrod's theory suggests a more useful model. Explicit focus can contain more than seven plus or minus two tokens, each with different salience. I suggest that classical studies have measured the number of tokens that a person's explicit focus memory can keep at maximum salience — seven plus or minus two. Maximum salience of tokens is required to allow a person rote recall of arbitrary information, as tested in classical studies. However, Sanford and Garrod's theory supports the idea that explicit focus memory also supports other tokens at partial salience. There are several studies that show that people are far better at aided recall (recognition) than unaided recall (Shneiderman 1992). This suggests that, although a person's explicit focus can only sustain seven plus or minus two tokens at maximum salience at any one time, they can keep many other tokens partially salient at the same time.

Sanford and Garrod's theory can be used to explain how an interruption can make it difficult to resume preinterruption tasks. If explicit focus memory can only support seven plus or minus two maximally salient tokens, then an interruption will displace some or all of the original seven plus or minus two tokens into partial salience. These original seven plus or minus two tokens may still be relatively easily available in explicit focus memory, but since they have been reduced in salience, it will take effort to reactivate them when the interruption has passed. Since the preinterruption task(s) tokens still have partial salience in explicit focus memory, some kind of external reminders could help a person reactivate these tokens to maximum salience when they resume their preinterruption task(s).[6]

Long-term episodic memory is the total collection of currently inactive memories that a person has built or accessed during their current working session. Long-term semantic memory is all the rest of a person's memories that have not been accessed or referenced in the current working session. Both kinds of these latent memories require considerable effort and/or strong-cueing to activate and use.

THEORETICAL CONSTRUCT(S) about people (Sanford and Garrod 1981):

P28. People have four different kinds of memory: two kinds of active memory — (1) explicit focus and (2) implicit focus; and two kinds of latent memory — (3) long-term episodic, and (4) long-term semantic. These differences in kinds of memory represent cognitive structural differences that address a trade-off between memory accessibility and memory extent. These four kinds of memory can be ordered by: accessibility 1, 2, 3, 4; and extent 4, 3, 2, 1. Explicit focus memory is readily accessible but can contain very little information, and long-term semantic memory is difficult to access but can contain huge amounts of complex information.[7]

P29. People's explicit focus memory can contain several tokens at once. People dynamically maintain a level of salience associated with each token, which determines the token's accessibility.

[6] This idea of external reminders is supported by the research that says that people can recognize information more easily than they can recall it from rote. For example, people often find it useful to construct external physical reminders of things that they need to remember, e.g., tie a string around one's finger. Airline crews sometimes use a version of this idea to remind themselves to turn off the air conditioning units before lowering the flaps — they place an empty coffee cup upside down over the flap handle (Norman 1992, p. 167).

[7] These four categories of human memory show a similar trade-off between accessibility and extent as four categories of computer memory, For illustration, we can pair human memories with computer memories: explicit focus as a bank of CPU registers; implicit focus as RAM; long-term episodic as hard disk; and long-term semantic as DAT (digital audio tape).

P30. People can perform unaided recall of information in their explicit focus memory only if the relevant token has maximal salience.

P31. People are only able to maintain maximal salience on seven plus or minus two tokens in their explicit focus memory at any one time.

P32. People can perform recognition, or aided recall, of information in their explicit focus memory if the associated token has less than maximal salience.

P33. People do not have direct conscious control over the salience they ascribe to tokens in their explicit focus memory. Instead, the level of salience of tokens is a side effect of cognitive processing.

Adams and Pew use Sanford and Garrod's theory to explain how the structure and function of human memory affects the way airplane pilots can direct attention during multitasking. Adams and Pew hypothesize that the salience of memory affects the constructivist perception process. They say that because memories are used as filters to perceive and interpret new information, the accessibility (salience) of those memories will affect the perception and interpretation process. We use the word accessibility to refer to the relative effort and reliability of activating a particular memory.

In a difficult task, like flying an airplane (which requires situational awareness and multitasking), the user must jostle their memory resources back and forth between many demands. The person must constantly change the salience of tokens in their explicit focus memory. Since the person cannot support maximal salience on all relevant tokens in their explicit focus memory, giving immediate attention to a task(s) will cause its tokens to dominate in salience over the tokens of other tasks. This variance in salience between the groups of tokens associated with different tasks affects the perception process related to those tasks.

People will perceive and interpret new information relevant to tasks that have high salience tokens with ease and accuracy. However, people will perceive and interpret new information relevant to tasks with lower salience tokens with difficulty and inaccuracy. New information relevant only to inactive memories can only be perceived and interpreted with great effort. In a situation where time is short, like landing an airplane, people will totally ignore or inaccurately perceive new information irrelevant to the immediate task. (See the story about the uncompleted checklist (p. E-1)).

THEORETICAL CONSTRUCT(S) about people (Adams and Pew 1990):

P34. Those memories people allow to be most salient in their explicit focus memory affect the ease and accuracy of their perception and interpretation of new information. A person will more easily and accurately perceive and interpret new information that is relevant to whatever they are currently acting on than new information that is relevant to other pending tasks.

Adams and Pew reaffirm theoretical constructs P7 (p. 9), P8 (p. 9) and T1 (p. 10). However, they color these theoretical constructs differently than Tsukada et al. They adopt the perspective of focused attention upon external tasks instead of the perspective of internal vs external effort as Tsukada et al. P7 (p. 9) (people are limited to giving thoughtful, conscious attention to only one thing at a time), P8 (p. 9) (people accomplish complex multitasks by shifting attention from one task to another), and T1 (p. 10) (tasks can be accomplished by the accumulation of many independent noncontiguous efforts.

Adams and Pew elaborate on theoretical construct P9 (p. 10) (people internally attend to many things at the same time). They say what kinds of internal action a person can do in parallel. While a person performs one and only one external activity at a time, they simultaneously manage a queue that reflects the prioritization of other pending tasks. Adams and Pew use a metaphor of a queue to model this group of metainformation about pending tasks to imply that the task at the top of the queue will be executed next. A person orders their mental queue of pending tasks by the tasks' relative urgency in time and relevancy to the current context. A person must dynamically reorder this queue because the passage of time affects tasks' time requirements, and changes in situation affect tasks' relevancy and significance.

THEORETICAL CONSTRUCT(S) about people (Adams and Pew 1990):

P35. People can simultaneously perform external actions on one (and only one) task at a time while constantly and simultaneously maintaining subtle dynamic metainformation about other pending tasks.

THEORETICAL CONSTRUCT(S) about tasks (Adams and Pew 1990):

T4. Tasks have temporal requirements on their execution. This theoretical construct changes dynamically as time passes.

T5. The successful completion of a particular task has some level of importance or significance within a person's overall goals. This theoretical construct changes dynamically relative to changes in a person's environment and the execution of other tasks.

Maintenance of this internal metainformation is susceptible to human memory limitations and, therefore, requires effort and is prone to error. Adams and Pew say that a person's ability to successfully balance situational awareness and multitasking, e.g., flying an airplane, is dependent on their success at maintaining this metainformation. For people to coordinate situational awareness and multitasking, they must make good decisions about two things: (1) when to switch external effort between tasks and (2) what task to switch to next. These decisions rely completely upon a person's ability to maintain subtle metainformation about impending tasks.

A person's ability to maintain accurate metainformation about pending tasks depends upon their continual efforts to correctly perceive and interpret new incoming information. However, Adams and Pew remind us that processing new information takes much effort and can temporarily monopolize scarce memory resources. Although a person can maintain metainformation at the same time they exert focused attention upon some external task, they must stop their external activities to process new information. People cannot simultaneously perform external actions and process new incoming information. Adams and Pew (1990, p. 523) say that for people to process new incoming data, they must immediately interrupt whatever they are doing long enough to perceive the new information; then they may try to resume their interrupted activity.

THEORETICAL CONSTRUCT(S) about people (Adams and Pew 1990):

P36. The accuracy of metainformation that a person has maintained is positively related to their successful completion of multitasks. People use this metainformation when switching their external efforts between tasks. If a person has maintained accurate metainformation, then they will make good decisions about (1) when to switch focused attention to another task and (2) which pending task to act upon next.

P37. People must temporarily interrupt their focused attention on a task in order to switch their attention and refocus on the task of processing new incoming information (see P25 (p. 20)).

Adams and Pew report that mental shifts between topics or semantic domains have measurable costs to performance. Each time a person shifts their focus of attention from one task to another, they must expend time and effort and expose themselves to potential informational errors and biases (Anderson and Pitchert 1978; Bower 1982; Sanford and Garrod 1981; Schank et al. 1982).

THEORETICAL CONSTRUCT(S) about people (Adams and Pew 1990):

P38. Shifting focused attention from one thing to another has measurable costs in effort, time, and frequency of error.

Adams and Pew say that there is not yet a formal predictive theory that can accurately predict people's process of switching focused attention. However, even though there is not yet a refined theory, Adams and Pew say that there exists some useful information about how people switch focused attention. Further, they provide some terminology for describing the behavior of attention allocation. They say that it is useful to model people's process of focused attention switching with a probabilistic approach, instead of with a deterministic approach.

Adams and Pew (1990, p. 523) say that people have a variable degree of ease of switching their focused attention. Sometimes people will easily switch their attention between tasks, and at other times, they will have great difficulty switching between tasks. Adams and Pew propose that people are more likely to switch their attention when and to what is most easy.

THEORETICAL CONSTRUCT(S) about people (Adams and Pew 1990):

P39. People have a variable degree of ease of switching their focused attention relative to time and relative to their multitask requirements (individual differences).

2.5 Management of Semiautonomous Agents

Domain Specific Definition of Interruption: a costly side effect of delegating tasks to intelligent agents.

Delegation is a method by which one individual commissions another individual to act on their behalf. This method has been a standard operating procedure for all hierarchical human organizations; and more recently, as a model for client-server computer systems. Delegation is popular because it has been shown to be useful for accomplishing certain kinds of complex tasks. Some authors of computer science employ the idea of delegation to address the problem of overloading a human user.

It is common for human users to become overloaded while trying to perform some kinds of multitasks on computer systems. Job requirements can exceed a person's cognitive resources. Authors have proposed constructing intelligent software agents that can accept requests for delegation. A user can commission these intelligent agents to perform tasks on their behalf. Authors hypothesize that this ability to delegate responsibilities to intelligent agents will allow human users to avoid cognitive overload and successfully perform their multitasks.

A discussion of delegation is relevant here because one of the costs of delegation is increased interruption. A person does not free themselves from responsibility when they delegate a task to an intelligent agent.

Instead, they only trade one kind of responsibility for another. The person gives up the responsibility to do the task personally and accepts a new responsibility of supervising the performance of the task by an intelligent agent. These supervisory duties can be nontrivial.

Intelligent agents are usually constructed so that they are required to make reports and requests of their users. Since an agent is somewhat autonomous, its user is not required to focus attention on the agent while it is working. The human, instead, is allowed to concentrate on other tasks while the agent is working. This means that when the agent reports its progress or requests information from its user, it must first interrupt or distract its user from what he or she is currently doing. Thus, delegating a task does not totally free the user from cognitive demands related to that task (Kirlik 1993).

Kirlik (1993) authored a research paper in which he observed that the costs of delegating a task to a task-offload aid (an intelligent software agent) can sometimes outweigh the benefits. Kirlik reaffirms that people have a limited capacity to perform multitasks. And, because there are cognitive costs of delegation, it is possible for peoples' performance on a multitask to actually decrease if they begin delegating tasks to intelligent agents. It can sometimes take more effort to supervise an agent than to do the task without intelligent aid.

THEORETICAL CONSTRUCT(S) about tasks (Kirlik 1993):

T6. Tasks can be delegated from one individual to another.

T7. The delegation of a task begets a new task of supervision. When a user delegates a task, they give up the responsibility to perform the task themselves, but they gain a new task of supervision.

THEORETICAL CONSTRUCT(S) about people (Kirlik 1993):

P40. People have a limited capacity to perform multitasks. (This theoretical construct is somewhat superfluous, but I include it anyway, for completeness.)

P41. People have a limited capacity to perform supervisory tasks.

Kirlik says it is possible for people to reduce their workload and improve their performance on multitasks by delegating tasks to intelligent agents. However, the utility of delegation depends on the management strategy chosen by the person — people's managerial decisions affect the utility of their delegation decisions. "Of great importance is the strategy the operator develops for managing interaction with an aiding device. Human supervisory controllers have the capability and often the freedom to strategically manage their interaction with automation in an effort to keep both workload and system performance at acceptable levels" (Kirlik 1993, p. 222).

THEORETICAL Construct(S) about people (Kirlik 1993):

P42. People can successfully use delegation to perform multitasks. People can divide their responsibilities for the tasks that comprise their multitask into two categories: (1) tasks they perform personally and (2) tasks they delegate and supervise the performance by others. This means that people can simultaneously coordinate performing tasks personally and supervising performance of tasks by others.

P43. People know several varied managerial techniques for supervising the performance of delegated tasks.

P44. People can make strategic managerial decisions dynamically when supervising the performance of delegated tasks.

The managerial strategy a person chooses is critical to the success of their delegation attempts. Sheridan (1988) wrote a useful paper titled, "Task Allocation and Supervisory Control," in which he presents a broad overview of factors that affect people's selection of appropriate managerial strategies for supervising intelligent computer aids performing delegated tasks. Supervisory control systems incorporate intelligent computer aids to enable their users to accomplish complicated physical control tasks. The intelligent computer aids in a supervisory control system are intelligent software agents. However, these two fields (supervisory control systems and intelligent software agents) have different terminology because they traditionally address different domains. Research reported about intelligent software agents usually addresses information processing tasks, whereas research reported about supervisory control systems usually addresses control of physical processes.

Sheridan (1988, p. 159) explains the function of supervisory control systems. "The human supervisor works through the computer to effect what needs to be done in the physical world. The computer is then seen as a mediator — communicating upward to the supervisor, communicating downward to the physical process, whatever it may be." Typical domains of application include: control of vehicles (aircraft, spacecraft, ships), control of chemical and electrical power generating plants, and control of industrial and other robotic devices.

THEORETICAL CONSTRUCT(S) about people (Sheridan 1988):

P45. People can work through mediators. People can both act on tasks and perceive task performance at an abstract level through a mediator.

When people delegate tasks to intelligent aids, they also accept the costs of personally managing that delegation. One of these costs is potential interruption by the subordinate intelligent aid. Sheridan says there are three theoretical constructs that describe people's behavior while managing delegated tasks: (1) the kind of action the person is trying to accomplish with the intelligent aid; (2) the level of interaction abstraction provided by the intelligent aid; and (3) the degree of autonomy provided by the intelligent aid. A discussion of these theoretical constructs is important to our discussion of user-interruption, because it categorizes human behavior in supervisory control tasks (managing intelligent agents as they perform delegated tasks). This categorization of behavior gives us a theoretical tool for investigating the delegation process and the effects of interrupting human supervisors.

Sheridan says that there are twelve different categories of human supervisor functioning. These represent twelve different actions that people try to accomplish with intelligent computer aids. Sheridan further breaks down these twelve supervisory functions into five general classes. (Sheridan 1988, pp. 161-167) The following is partially quoted from Sheridan (1988, Table 1 p163).

(1) Plan [discover the function and effective use of an intelligent aid],
(1a) understand controlled process,
(1b) satisfice objectives,
(1c) set general strategy, and
(1d) decide and test control actions.
(2) Teach [provide an intelligent aid with the information it needs to perform a delegated task],

(2a) decide, test, and communicate commands.
(3) Monitor Auto [monitor automatic execution of the programmed actions],
(3a) acquire, calibrate, and combine measures of process state,
(3b) estimate process state from current measure and past control actions, and
(3c) evaluate process state; detect and diagnose failure or halt.
(4) Intervene [respond to a failure or halt condition],
(4a) if failure: execute planned abort, and
(4b) if normal end of task: complete.
(5) Learn [learn from current experience to use the intelligent aid better in the future],
(5a) record immediate events, and
(5b) analyze cumulative experience.

People interact with intelligent computer aids at different levels of abstraction. Sheridan says that there are different ways of controlling a process. The nonabstract way is to skip the intelligent aid and manually control the process oneself. The abstract ways are to delegate the control task to an intelligent computer aid and then interactively supervise that aid. People communicate with intelligent aids in one of three levels of abstraction: (1) knowledge-based (high-abstract); (2) rule-based (medium-abstract); or (3) skill-based (low-abstract). Sheridan describes these differences in interaction abstraction with the following model, shown in Fig. 4.

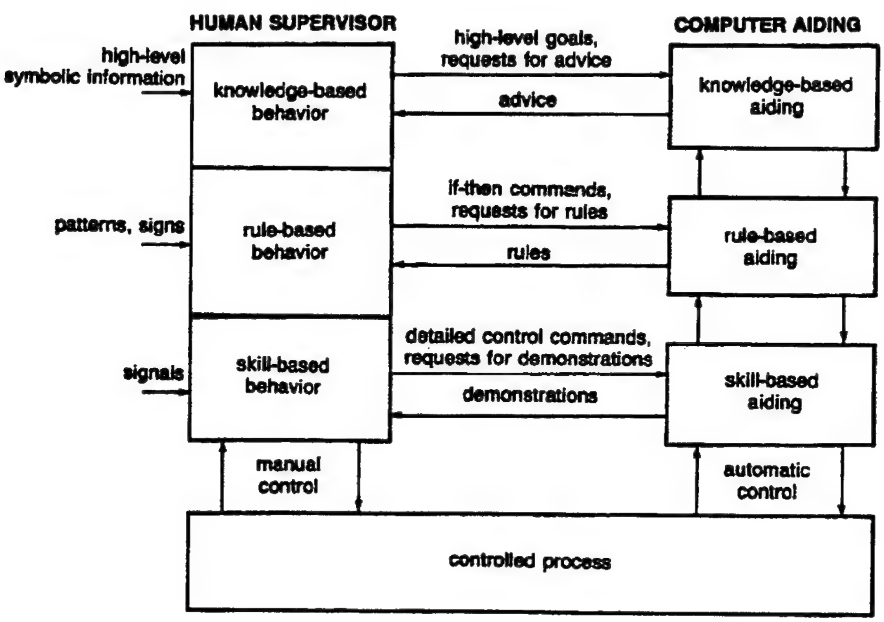

Fig. 4 — Sheridan's model of the different levels of interaction abstraction between a human supervisor and their intelligent computer aid. Reproduced from (Sheridan 1988, p. 168).

Sheridan's third theoretical construct of human supervisory behavior is the degree of autonomy provided by the intelligent aid. People choose different managerial strategies depending on the degree of

autonomy exhibited by the intelligent computer aid. Sheridan classifies the autonomy of intelligent computer aids along two dimensions: capacity to act autonomously and accountability for actions. An intelligent computer aid has some degree of capability to automatically perform the different stages of a task (determine potential alternative approaches, select one approach to execute, implement the chosen approach, and inform the human of the results). The capacity of an aid determines: which parts of a task the human must do unaided; which parts of the task the aid does autonomously; and which parts the human and aid must perform cooperatively. An intelligent computer aid also has a degree of accountability toward its user. This defines who is given ultimate responsibility for accomplishing tasks — human or machine.

Sheridan (1988, p. 171) gives ten examples of supervisory interaction to illustrate his classification of automation. Each example shows an increasing degree of automation.

(1) Human does the whole job up to the point of turning it over to the computer to implement.
(2) Computer helps by determining the options.
(3) Computer helps determine options and suggests one, which human need not follow.
(4) Computer selects action and human may or may not do it.
(5) Computer selects actions and implements it if human approves.
(6) Computer selects action, informs human in plenty of time to stop it.
(7) Computer does whole job and necessarily tells human what it did.
(8) Computer does whole job and [if asked] tells human what it did.
(9) Computer does whole job and [tells human only if it decides to].
(10) Computer does whole job if it decides it should be done and, if so, tells human if it decides he [or she] should be told.

THEORETICAL CONSTRUCT(S) about people (Sheridan 1988):

P46. There are three factors that affect people's choice of managerial strategy when employing intelligent computer aids: (1) their purpose for employing the agent; (2) the level of abstraction with which they will interact with the agent; and (3) the degree of autonomy provided by the agent.

P47. People use intelligent computer aids for different purposes. These different purposes can be categorized into five general categories: (1) discover the function and effective use of an intelligent aid; (2) provide an intelligent aid with the information it needs to perform a delegated task; (3) monitor automatic execution of the programmed actions; (4) respond to a failure or halt condition; and (5) learn from current experience to use the intelligent aid better in the future.

P48. People interact at three different levels of abstraction with subordinate intelligent computer aids (knowledge-based level; rule-based level; or skill-based level).

THEORETICAL CONSTRUCT(S) about context (Sheridan 1988):

C1. Intelligent computer aids provide different degrees of autonomy along two dimensions: capacity to act autonomously and accountability for actions.

2.6 Human-Human Discourse

Domain Specific Definition of Interruption: an example of human-human discourse that can be represented and analyzed with the theory of discourse analysis.

Authors have published useful theory of human-human interaction under the title of discourse analysis. This theory addresses the problem of modeling and analyzing occurrences of human-human interaction. The proposed theory of interaction can be extremely useful for addressing this difficult domain. Occurrences of human-human interaction are complex processes and, therefore, can be difficult to study. Interaction events are composed of all behaviors and their interrelationships, which happen across several different dimensions: abstraction, media, time, scale, and individual participants.

The theory of discourse does not address specific kinds of human-human interaction, such as events of people interrupting other people. Instead, this theory addresses the metalevel problem of how to represent and analyze the total complexity that is in every kind of human-human interaction. This theory is useful, because the patterns of human-human interaction are powerful models for studying human-computer interaction. Therefore, we can apply this theory of discourse to conduct detailed modeling and analysis of occurrences of people interacting with computers, and this includes the specific kind of human-computer interaction which is the topic of this report — computers interrupting people.

Theory of discourse proposes to model human-human communication in context for the purpose of studying the communication of meaning between people. "Essentially, then, discourse analysis is an analysis of meaning but meaning seen not in the traditional philosophical or semantic sense of isolated concepts but rather the discourse analyst studies meaning as a construct of interaction, and he [or she] studies the various ways in which we create, relate, organize, and realize meaning in behavior" (Riley 1976, p. 2).

Riley (1976) in his paper titled "Discursive and Communicative Functions of Non-Verbal Communication," presents a theory of human discourse that emphasizes the previously unappreciated importance of nonverbal communication acts. Riley says that spontaneous, authentic, face-to-face informal interaction between people can be modeled as a complex interdependent fabric of diverse communication acts. These communication acts are realized by a large variety of behaviors, e.g., language, tone of voice, gesture, posture, body movements, spatial orientation, physical proximity, eye contact, and facial expression (Riley 1976, p. 2). Riley says that it is important to model all these kinds of behaviors because people use them all together to express meaning, i.e., language by itself is not enough. This is the total context of communication.

Riley provides a way for all human dialogue behaviors to be represented within the same descriptive theory. This unifying theory embodies two useful concepts: (1) verbal behaviors do not deserve a special and separate status in discourse analysis and (2) that all discourse behaviors can and must be represented in a consistent way. This consistency and uniformity of representation allows us the freedom to express the complex interdependencies expressed in human interaction without being tied to the artificial and misleading "verbal or nonverbal" classification.

Riley uses a theoretical concept that can easily and uniformly model all kinds of dialogue behaviors — the communication act. A communication act is a basic unit of meaning, with which people attempt to express to other people. People **realize** their communication acts by a wide range of **behaviors,** which are **conveyed** along different **channels** of communication. Therefore, people can express a single meaning in any of several different ways — a particular communication act can be realized in different ways by different behaviors and conveyed along different channels. This distinction between meaning and its expression and its conveyance is useful for untangling the complexities of human interaction.

For example, speaking a word is a particular realization of a communicative act or a "speech act." Riley says, "a speech act is just one of the possible realizations of a communicative act: a shake of my head can communicate disagreement just as efficiently as the word 'No.' Indeed, so can the right intonation or key choice, so can facial expression and certain gestures. And of course this is an extremely crude example: the meaning of an act of communication is much more often the product or sum total of a head movement plus words plus intonation and key, plus facial expression, plus skeletal disposition, plus all the relevant situational features; meaning is the relationships, if you like, between all these features" (Riley 1976, p. 3).

THEORETICAL CONSTRUCT(S) about people (Riley 1976):

P49. All aspects of people's communicative behavior are important and relevant to model and analyze the discourse and interaction between people. Speech alone is grossly insufficient.

P50. People interact with other people by the coordinated expression of interrelated sets of basic units of meaning — communication acts.

P51. People realize communication acts by various behaviors which are conveyed along different channels of communication. (Note as especially important this distinction between the meaning, behavior, and channels of conveyance.)

Riley expresses dissent from the popular assumption that verbal-vocal behaviors are relatively more important to communication modeling and analysis than other behaviors. Riley reviews the traditional categorization of human interactive behavior along the verbal and vocal dimensions. This categorization of human interactive behavior reveals three domains (or components) of linguistic research: verbal, paralinguistic, and kinesic (see Table 1). Riley says that the verbal component should not be esteemed more important than the other categories. He says that in a unified theory of discourse, these three categories must be of equal importance.

Table 1 (Riley 1976, p. 3) shows the traditional categorization of research into human interactive behaviors. People's behaviors are categorized along the verbal and vocal dimensions. I provide an example of each in parentheses.

Table 1 — Traditional Components of Discourse

	verbal	**nonverbal**
vocal	verbal component (speak the word "hello")	paralinguistic component (speak the nonword "um")
nonvocal	("sign" a word of sign language)*	kinesic component (make the nonword gesture of pointing to an object)

* Riley leaves the nonvocal-verbal category vacant. It is irrelevant to this discussion because Riley states that this is not a useful categorization; however, for completeness there is at least one important example of verbal nonvocal behavior expressed by humans — sign language. Deaf people, fluent in sign language, are perfectly capable of communicating verbal information nonvocally.

Riley supports his assertion that kinesic behaviors are a critical part of discourse analysis by presenting a taxonomy of kinesic behaviors that classifies different expressions of communication acts. He shows that without including these previously devalued dialogue behaviors in our model, we cannot successfully model and analyze human interaction. Discourse analysis must include a representation of these communication acts. (I include a summary of Riley's taxonomy of kinesic behaviors here because I believe that kinesic behaviors are an important class of behaviors for modeling and analyzing the human dialogue of interruption.

Riley's taxonomy has three groups of kinesic behaviors: emblems, indices, and gestures. **Emblems** are behaviors that people consciously and intentionally perform to convey conventional, specific meanings that are easily expressed in words. For example, "thumbs up" or "the finger." **Indices** are behaviors that people make to convey indexical information (information about the person making the behavior). There are three kinds of indices: psychological, social, and biological. Psychological indices are realizations of communicative acts about the state of the person's psychological state (e.g., smiling, weeping, sweating, blushing). Social indices are realizations of communicative acts about a person's social state (e.g., class, occupation). Biological indices are realizations of communicative acts about a person's physical self (e.g., age, sex, health, fatigue).

Gestures includes all kinesic behaviors that are not easily categorized as emblems or indices. The following list contains different kinds of gestures.[8]

(1) Kinematopoeia. These behaviors are realizations of communication acts to illustrate something. For example, holding one's hands far apart while speaking "I caught a fish this big."[9]
(2) Deictics. These behaviors are realizations of communication acts to refer to something. For example, tipping one's head in the direction of an object while speaking "hey, look at that!"
(3) Gestures having illocutionary force. These behaviors are physical realizations of communicative acts that convey content meaning in a conversation. These communication acts are used to convey many kinds of meaning:
    - agreement or disagreement, e.g., nodding or shaking one's head;
    - greeting, e.g., an eyebrow flash;
    - declining, e.g., placing one's hand over a cup when offered more coffee;
    - requesting, e.g., asking for the time by tapping one's wrist where a watch should be;
    - commanding, e.g., a policeman signaling traffic;
    - doubting, e.g., an appropriate facial expression; and
    - reporting ignorance, e.g., shrugging shoulders (Riley 1976, p. 9).

[see footnote[10]]

(4) Turn-taking signals. People use these gestures as realizations of communicative acts to regulate the process of turn giving and taking between the people in a discourse. For example, eye gaze is often used by people to indicate when they are prepared to relinquish a turn.
(5) Attention signals. These behaviors are realizations of communication acts to regulate the conversants' attention. For example, eye gaze directed at someone outside of the current dialogue group.
(6) Address signals. These behaviors are realizations of communication acts by a person to select

[8] I tend to repeat myself about Riley's assertion that behaviors are realizations of communicative acts intended to convey some particular meaning. My repetition of this point is not good English, but I think it is necessary to remain clear about Riley's motivations.

[9] My examples for kinesic behaviors are the common US English meanings of these gestures.

[10] Gestures 4, 5, and 6 are kinesic behaviors that people make as realizations of communicative acts to regulate the interaction itself. These comprise metacommunication.

and indicate their listeners. For example, alignment of head direction, eye gaze, and posture toward another person selects them as a listener.

Of all kinesic behaviors, there are three kinds of gestures that are particularly relevant to the phenomenon of interruption: turn-taking signals, attention signals, and address signals. Each of these physical behaviors is a realization of a person's communication act to regulate or manage the process of interaction at a meta level.

THEORETICAL CONSTRUCT(S) about people (Riley 1976):

P52. People have three different methods for expressing their communication acts: verbal, paralinguistic, and kinesic. (Note: I would add a fourth method here — a nonvocal verbal component. This component describes peoples' discourses by expressions of standard sign languages.)

P53. People have three different methods for kinesic expressions of communication acts: emblems, indices, and gestures.

P54. People make some communication acts at a metalevel of meaning in order to guide the process of interaction.

P55. People make gestures of turn-taking signals as realizations of communication acts to regulate turn-taking in their interaction with other people. Examples of these behaviors can be expressed with: eye gaze, change in speech timing, synchronized finishes of verbal and kinesic behaviors, creaky voice, low key voice, or cessation of kinesic behaviors.

P56. People make gestures of attention signals as realizations of communication acts to regulate the attention of all people involved in the interaction.

P57. People make gestures of address signals as realizations of communication acts to regulate who their listeners are and are not.

Riley (1976) asserts that kinesic dialogue behaviors comprise a critical part of the dialogue process and, therefore, must be included in dialogue analysis. The traditional distinction between verbal and nonverbal behavior (Table 1, p. 31), carries unnecessary confusion into discourse analysis. This distinction confounds the separation of meaning, expression, and conveyance. This confusion allows our irrational bias toward verbal behaviors to affect our ability to successfully model and analyze human interaction. It is much more useful to separate meaning from its expression and its conveyance. Therefore, the vocal/nonvocal, and verbal/nonverbal distinctions are inappropriate. Riley (1976, p. 4) says that the use of this inappropriate categorization has traditionally resulted in confusion between two different measures of people's discourse behaviors: (1) the degree of linguisticness and (2) the importance in communicative function.

Riley proposes a "unified or integrated model for the description of discourse." This unifying theory uses the concept of "communication act" as its basic unit of construction. This basic and uniform modeling tool affords representation and analysis of all discourse behaviors as potentially important to discourse at some level. Riley also proposes that all communication acts should be analyzed along three distinct levels: the realization level; the communicative level; and the discursive level. He says that these three levels capture the most useful categorization of discourse analysis. Riley (1976, p. 13) asserts these three levels of analysis are equally important for successfully analyzing dialogue.

The realization level of analysis addresses the mapping between all observable discourse behaviors (verbal, paralinguistic, kinesic) and the communication acts or meaning which those behaviors realize. This level of analysis is critical because it provides us with information about how people are realizing their communication acts. We discover how different behaviors are being used in concert to express meaning.

The communicative level of analysis addresses the illocutionary forces of communication acts (separate from their particular realization). This level of analysis provides us with information about the communicative intentions of the conversants, e.g., inviting, persuading, agreeing. Note that there is no one-to-one relationship between the illocutionary forces and the individual behaviors of realization.

The discursive level of analysis address people's attempts to regulate or manage the process of interaction at a metalevel, e.g., interactional tactics, turns, attention direction, address, relative distribution of utterances. Note also that there is no one-to-one relationship between discourse regulation and the individual behaviors of realization. We observe people's myriad discourse behaviors all woven together into a complex fabric. However, Riley's three levels of analysis allow us to extract specific information about two parts of people's communication acts: (1) their meaning — both illocution (communicative level) and dialogue regulation (discursive level) and (2) their chosen methods of expression (realization level). (Note: Riley relies on his "realization level of analysis" for extracting information about the "channels of conveyance" part of communication acts.)

THEORETICAL CONSTRUCT(S) about people (Riley 1976):

P58. People intermix their expression of discourse behaviors so that their physical realization of meaning, their attempts at illocutionary force, and their attempts to regulate the process of interaction are all interwoven into a complex fabric of communication.

Riley's theory of discourse analysis gives us a powerful tool for analyzing human discourse relevant to this report — the interruption of people. When we apply this theory, we see that for one communication act of interruption, it is possible to have more than one physical realization as discourse behavior. Indeed, it seems reasonable that there are a multitude of different behaviors and combinations of behaviors that can realize an interruption. For example, a person might interrupt another with the coordinated and synchronized expression of all the following behaviors together: speaking "excuse me please;" turning the head toward the other person; moving the eyes to make eye contact with the other person; reaching out an arm and hand to make a gesture similar to blocking the progress of something; moving closer to the other person; smiling; and then synchronized cessation of all movements and behaviors to indicate a change in turn to allow the other person to acknowledge this interruption request.

Riley's theory also allows us to differentiate between people's illocutionary forces and their meta dialogue discursive attempts. This is useful because people's behaviors intended to interrupt and those intended to convey meaning are intermixed. Riley's unified theory gives us a tool for separating those behaviors.

Riley's theory is useful in several ways, however it does not solve everything. There are some notable weaknesses or deficiencies to Riley's unifying theory. His theory does not provide structures for modeling interrelationships between individual communication acts or interdependencies between their behavioral realizations. Also Riley's theory does not provide temporal structures for modeling the coordination between communication acts or their behavioral realizations over time. This theory also does not provide useful methods to aid the difficult analysis task of discovering the abstract communication acts of human conversants' observable behaviors.

2.7 Human-Human Dialogue

Domain Specific Definition of Interruption: a common and normal part of human-human dialogue behavior.

Taylor and Hunt (1989) report the results of a workshop titled "Flexibility versus Formality." This workshop produced a discussion of requirements for a formalism for the design of multimedia human-computer dialogues. The workshop participants used human-human dialogue as a metaphor to identify requirements of human-computer dialogue. They began with the postulate that people's behavior in human-computer dialogue is similar to their behavior in human-human dialogue.

Taylor and Hunt say that some common human interaction behaviors are not well formalized as dialogue "turns." People frequently interrupt communication dialogue: (1) they interrupt themselves by breaking off their turn before completing a sentence, and (2) they interrupt other people by initiating a dialogue turn during another person's turn. Taylor and Hunt illustrate how frequently people interrupt themselves during human-human dialogue with the following real-life dialogue (Taylor 1989, p. 444) (the participants are discussing a forthcoming nasal operation):

S: Do you know what they're doing?
K: I think they take these poles and they just sort of (giggle) ...
S: (giggle) violently knock your ...
K: That's right. I think they're ... Basically it's like breaking inside, I think.

Taylor and Hunt say this example dialogue shows that interruption is a very common and normal part of dialogue. "In this little interchange, only three of the six potential sentences are completed, and to an uninvolved observer, the three broken ones do not appear to convey the necessary information. Obviously, however, from the viewpoint of the participants, the information is adequate. They seem to be quite happy with the interchange, which is experienced as well-formed. Interruption should be seen as an integral part of the dialogue process, not as some kind of irregularity that can be swept aside when analyzing "real" conversation" (Taylor and Hunt 1989, p. 444).

Taylor and Hunt say that there are two other common dialogue behaviors that are difficult to model with the "turn" concept: sidechannel contributions and abort or emergency stops. Taylor and Hunt propose that a formalism for human-computer dialogue must have modeling structures to represent interruption, sidechannel contributions, and aborts as normal (first class) parts of dialogue. People express sidechannel contributions as feedback to the person they are attending. These expressions are provided to inform the communicator of the success and failure of their attempts to communicate. For example, while someone is speaking to me, I simultaneously communicate feedback to them — I say things like "uh-huh" or "yea" or make nonverbal gestures to mean that I hear and understand.

Sometimes a person aborts or abruptly quits a dialogue altogether. Taylor and Hunt say that this normal human behavior can cause serious problems in a human-computer dialogue if the computer has not been designed to support such behavior. A formalism for human-computer dialogue should include methods for explicitly dealing with the event of a person aborting the dialogue.

THEORETICAL CONSTRUCT(S) about people (Taylor and Hunt 1989):

P59. People exhibit common and normal communication dialogue behaviors that are not well formalized as dialogue "turns." These behaviors emphasize the dynamic nature of dialogue. Three important examples are: (1) interruption of self and others; (2) sidechannel contributions; and (3) abort.

2.8 Psychology of Human Attention

Domain Specific Definition of Interruption: the method by which a person shifts their focus of consciousness from one processing stream to another.

Davies, Findlay, and Lambert have written a paper titled, "The Perception And Tracking Of State Changes In Complex Systems" (Davies et al. 1989). They apply psychological theories of human attention in their research about the display design of interactive computer systems. Davies et al. address the task environment in which a user must maintain situational awareness of a complex, multiactivity process. Since they specifically address the user's need to switch attention between different monitoring tasks, some of the theoretical concepts they advocate are useful in our attempt to define the phenomenon of interruption.

People can execute several simultaneous cognitive processing streams. This allows people to perform cognitive processing on several topics at once. However, there is an important structural restriction. People's cognition supports only one principle processing stream. The remaining processing streams must be executed as subsidiary or peripheral streams. This restriction means that although people can execute several cognitive processes at once, they can perform only one activity (thought or action) at a time with conscious control and awareness. (Miyata and Norman (1986) present a similar excellent survey of the psychology of human attention and how it is useful for studying user multitasking in HCI.)

This theory has two interesting implications: (1) people are limited to one conscious activity at a time, and (2) people perform a large amount of cognitive processing outside of their conscious control and awareness. Davies et al. say that evidence of this theory is observable because information produced by people's subsidiary processing can dynamically influence their primary processing. "One example of this is evidenced by our ability to elicit changes in the orientation of focal attention in response to changes in the peripheral visual field. Such parallel processing is used dynamically. Studies of the reading process show that detailed textual information is received from quite a small region to where gaze is directed. However, less detailed information (word boundaries, initial letters or words, and so on) is also being simultaneously assimilated from more distant regions to facilitate eye guidance and to provide some preliminaries to more detailed analysis" (Davies et al. 1989, p. 511; Rayner 1983; Rayner 1992).

Davies et al. say that people have one focus of consciousness (a structure of their cognition). Whatever processing stream a person executes in their focus of consciousness becomes that person's principle processing stream. Therefore, a process is either principle or subsidiary depending on whether a person executes it inside or outside of their focus of consciousness. Human attention behavior can be usefully modeled as the result of the meta-activity of shifting processing streams into and out of a person's focus of consciousness. (Note that one important implication of this model is that processing streams continue to execute whether they are in the focus of consciousness or not. When a person switches their attention from one activity to another, the displaced processing stream continues to execute but out of consciousness.)

Davies et al. propose that interruption is the exclusive method by which a person switches processing streams into and out of their focus of consciousness. Further they say that "conscious human activity can be viewed as consisting of bouts of processing which are terminated at an 'interrupt'" (Davies et al. 1989,

p. 512). This approach makes interruption a basic or pivotal concept for modeling the behavior of human attention.

Interruptions can be either internal or external. An internal interruption is a request by a subsidiary processing stream to be switched into the person's focus of consciousness. An external interruption is an event that triggers a subsidiary processing stream to request to be switched into the person's focus of consciousness. An external interruption might come from another person, ex., a telephone call or physical arrival; or an external interruption might come from the person themselves, ex., a physical reminder, like a sticky note, or an alarm clock buzzer.

THEORETICAL CONSTRUCT(S) about people (Davies et al. 1989):

P60. People can execute several simultaneous cognitive processing streams.

P61. People have only one focus of consciousness. This is a unique cognitive structure that adds special support to one and only one processing stream at a time, i.e., conscious awareness and control.

P62. People have conscious awareness and control over only one activity (thought or action) at a time, i.e., whichever processing stream a person currently executes in their focus of consciousness. This is called the person's principle processing stream. The rest of a person's processing streams (those not executing in the focus of consciousness) are subsidiary and execute out of conscious control and awareness.

P63. People perform a large amount of cognitive processing outside of their conscious control and awareness.

P64. The information products of subconscious cognitive processing (subsidiary processing streams) can dynamically affect people's conscious cognitive processing.

P65. Human attention behavior is the result of the person's cognitive meta-activity of shifting processing streams into and out of their focus of consciousness.

P66. Subsidiary processing streams are not suspended but continue to actively process information out of conscious awareness and control.

P67. Interruption is the exclusive method by which a person switches processing streams into and out of their focus of consciousness.

The cocktail party phenomenon (Cherry 1953; Preece et al. 1994, p. 100) is a lucid example of people's cognitive attention behavior. The cocktail party is an environment that is over saturated with external events competing for attention. This is informational chaos. The senses of the people attending the party are overwhelmed with a tumult of incoming signals: many loud voices saying different things; a myriad of other sounds, noises and music; many attractive people wearing interesting clothing and jewelry; manifold physical gestures; multiple simultaneous eye contacts; people arriving, leaving and moving within the crowd; smells; tastes; and touches as people accidentally jostle each other (Preece et al. 1994, ch5.1).

People are fully capable of focusing on one stream of information amid such chaos. At first entering such an environment, people experience the chaos itself but can quickly become involved in one conversation with one group. They continue to experience the chaos, of course but they can extract one thread of

human conversation from the chaos and pull it into their focus of conscious attention. They also simultaneously keep the rest of the chaos out of their focus of conscious attention.

However, it is clear from people's behavior that they process a tremendous amount of information subconsciously. For example, while a person consciously attends one conversation, they can notice the utterance of their own name spoken within some other distant conversation. They can then instantly switch their conscious attention from their current conversation to that other conversation where their name was spoken. Thus, while people consciously attend to one thing they are also simultaneously subconsciously attending to many many other things.

We can use the theoretical concepts of human attention to explain people's behavior at cocktail parties. This theory tells us that people can simultaneously process many streams of information but that only one stream can execute in a person's focus of consciousness. A person chooses one stream to execute in their focus of consciousness, and they begin consciously participating in one particular conversation of the cocktail party. They also continue to subconsciously work on several other subsidiary processing streams coming out of the chaos. At some point, one of their subsidiary processing streams recognizes something that it perceives as important to their conscious awareness, and a metacognitive activity occurs to switch that subsidiary processing stream into their focus of consciousness. The processing stream that is displaced from the focus of consciousness continues processing now as a subsidiary processing stream.

THEORETICAL CONSTRUCT(S) about people (Cherry 1953; Preece et al. 1994, p. 100):

P68. People can select and focus on one stream of information amid dense informational chaos.

P69. People can extract several discrete streams of information simultaneously from dense informational chaos.

P70. People can subconsciously determine the relevancy and importance of the information they process in their simultaneous subsidiary processing streams. If needed they can perform the metacognitive activity of switching the important subsidiary processing stream into their focus of consciousness.

Preece et al. (1994, ch. 5.1) summarizes other useful concepts from attention theory — focused attention and divided attention. Focused attention describes human behavior in which a person tries to consciously attend to one information stream to the exclusion of all other competing stimuli. The cocktail phenomenon is an example of a context where people exhibit focused attention behavior. Divided attention describes human behavior in which a person is attempting to consciously attend to two or more things at the same time. Driving a car while participating in a conversation with a passenger is an example of divided attention behavior. The concept of divided attention does not imply that people have more than one focus of consciousness. Instead, it describes a kind of human cognition in which a person attempts to share their focus of consciousness between two or more processing streams by continuously alternating them into and out of their focus of consciousness.

Preece says that people's metacognitive decision to switch from one processing stream to another can be either voluntary or involuntary. A person makes a voluntary attention switch when they make a conscious decision to switch from their current activity to something else. However, some kinds of events can cause a person to change their attention without conscious decision — involuntary attention switch. For example, the occurrence of a loud noise can cause an involuntary switch of attention.

THEORETICAL CONSTRUCT(S) about people (Preece et al. 1994, ch. 5.1):

P71. People can maintain conscious awareness of two or more things at a time (divided attention) by continuously and alternately switching the relevant processing streams into and out of their focus of consciousness.

P72. A person's metacognitive decision to switch from one processing stream to another can be either voluntary or involuntary. This difference in behavior depends on people's environment.

P73. Information streams have characteristics each with an associated degree of salience.

2.9 A Metaphor of Cognitive Momentum

Domain Specific Definition of Interruption: something that extinguishes a person's cognitive momentum when they are performing concentrated work on a complex task.

Sullivan (1993) proposes an intuitive, nonscientific, definition of the interruption phenomenon. Sullivan used a metaphor of energy to express how interruptions are disruptive to performing work. He says that people build cognitive momentum in the performance of a task. An interruption, like a telephone call, can extinguish that momentum.

People have several different cognitive resources they use in concert to accomplish complex tasks. However, to accomplish demanding tasks, people must first exert concentrated effort to access and align these essential cognitive resources. There is an initial stage where people expend effort but do not accomplish any external portion of the task. People must first internally coordinate their cognitive resources before they can begin doing external work. This coordination of cognitive resources is a kind of cognitive momentum. People exert mental effort to get their cognitive resources into proper alignment once, and then that alignment propels itself forward as the person performs that task.

If person is interrupted after they have organized their cognitive resources, they lose their cognitive alignment. The start-up effort they invested is lost. Once the interruption finishes, they must regain their momentum before they will be able to resume doing work. They must recommence the process of gaining momentum.

THEORETICAL CONSTRUCT(S) about people (Sullivan 1993):

P74. People have various cognitive resources that they must align in task-specific ways in order to use these resources in concert to accomplish complex tasks. In order for a person to accomplish a complex task, their various cognitive resources must be able to coordinate and cooperate with each other.

P75. People must exert concentrated effort over time to align their various cognitive resources. After a person has labored to align their cognitive resources, their alignment carries itself forward (like momentum) as they perform the task. Interruption, breaks a person's alignment; and they must exert much cognitive effort to re-align their resources before they can resume work on the task.

2.10 Social Psychology of Conversation

Domain Specific Definition of Interruption: a violation of people's conversational rights.

One way people interact with other people is through dialogue. People use dialogue to communicate their knowledge and wants to each other, however, they also use dialogue to affect their social relationships with each other. People assert their own worth or status when they interact with others. This potential for social influence is one reason why the United States of America has a "freedom of speech" amendment in its Constitution. Governments usually recognize the social power of communication and create, maintain, and execute laws to control or prevent control of the flow of that power.

People have many ways to assert social influence with dialogue — some of these ways address the "message," and some of these ways address the "medium." People can advance their social importance or status by making useful contributions to dialogue. These contributions provide useful knowledge or meaning to some topic of conversation. If a speaker makes a useful contribution, their audience may change its perception of the speaker's social value in a favorable way and begin to esteem the speaker more highly.

People are also able to wield social influence by directly affecting the dialogue process itself— without making any meaningful contribution to dialogue whatever. People will graciously allow themselves to be interrupted by someone whom they hold in high esteem, however this principle can also work in reverse. If a person with lower social status is allowed to interrupt the speaker, then the listeners, and/or the speaker themselves may positively change their belief in the interruptor's social worth. The listeners (and/or the interrupted speaker) may need to internally rationalize their own passivity at allowing the speaker to be interrupted. They may justify their passivity by saying to themselves, "I wouldn't have permitted the speaker to be interrupted unless the interrupting person were of high social status. Therefore I must actually have a higher opinion of the interrupting person than I had realized." The result is that the interruptor gains social prominence.

If we ascribe to the ideal that people's social status should depend directly upon their social usefulness, then we may conclude that it is "unfair" for a person to gain social standing by only affecting the dialogue process and not by making contributions of useful knowledge. Most people do implement this notion of "fairness" in conversation, and this application of "fairness" leads to the concept of conversational rights.

West (1982) says that people have conversational rights and that being interrupted while speaking is a violation of those rights. West addresses the topic of how women increase or decrease their social rank in the work environment by the way they react to violations of their conversational rights. West explains that there are individual differences between males and females in the way people perceive interruption. West makes a case that if a woman wants to gain social status in the workplace, she must address interruption events in ways that her male coworkers will appreciate.

THEORETICAL CONSTRUCT(S) about people (West 1982):

P76. People combine dialogue with attempts to influence social relationships between each other. Dialogue between people serves as more than just a mode of communicating knowledge or needs. Dialogue also serves as a means for people to affect the social relationships between them.

P77. People can use dialogue to influence social relationships in two ways: (1) by making useful contributions of meaning and (2) by controlling the dialogue process itself through metadialogue regulation techniques.

P78. People recognize the concept of conversational rights. Interruption is a violation of conversational rights in which the interrupting person attempts to use a metadialogue regulation technique to affect the conversants' social standings.

P79. People sometimes need to internally justify their response to interruption. For example, suppose that one person interrupts another during a dialogue. If the interrupted speaker and/or the other listeners do not try to prevent this violation of the speakers conversational rights, they may need to later internally justify their passive behavior. This internal justification may have three possible outcomes: (1) they may convince themselves that the interrupting person has the high social status to merit such behavior; or (2) they may convince themselves that the interrupted person has the low social status to merit such behavior; or (3) both 1 and 2.

These theoretical constructs about people have significant social psychological implications for the design of human-computer interfaces. HCI system designers must be careful not to build computer systems that interrupt their users in ways that habitually violate their users' conversational rights. This kind of HCI design error would result in an ineffective and oppressive computer system.

2.11 Interactional Sociolinguistics of Politeness

Domain Specific Definition of Interruption: a face-threatening act.

People maintain social relationships with other people (e.g., see P76 (pg 38)). An important way they do this is by deliberately controlling the way they express their communication acts. This deliberate control of expression is especially critical for interrupting people. Interruption is an inherently dangerous kind of communication act because of its potent social effect. Therefore, people very carefully package their communication acts of interruption so as not to damage their social relationships. This great care people take in constructing appropriate expressions of interruption is an important source of information for how we should create the HCI of user-interruption.

Brown and Levinson (1987) propose a theoretical tool for studying how people structure their communication acts for social effect. They say that people construct their communication acts in particular ways with which they intend to have specific social effects. Brown and Levinson propose a theory of interactional sociolinguistics that provides useful tools for studying how people construct their expression of communication acts for social effect.

> "We believe that patterns of message construction, or 'ways of putting things,' or simply language usage, are part of the very stuff that social relationships are made of (or, as some would prefer, crucial parts of the expressions of social relations). Discovering the principles of language usage may be largely coincident with discovering the principles out of which social relationships, in their interactional aspect, are constructed: dimensions by which individuals manage to relate to others in particular ways" (Brown and Levinson 1987, p. 55).[11]

[11] Brown and Levinson's theory explains that interruption is one kind of communication act (a kind of face-threatening act), and that the way the interruption is expressed determines its effect on social relationships.

Brown and Levinson propose an abstract model of a person they call the Model Person (MP). They employ the structure of their Model Person to explain systematic dialogue structures used by interacting people to influence social relationships.[12]

The Model Person is relatively simple — it consists of only a few structures and rules. "All our Model Person (MP) consists in is a willful fluent speaker of a natural language, further endowed with two special properties — rationality and face" (Brown and Levinson 1987, p. 58). Rationality gives the MP a predictable method of creating plans of communication actions to accomplish its social goals. Face endows the MP with two kinds of desires (or face-wants) ascribed by interactants to themselves and to one another: (1) the desire to be approved of (positive face) and (2) the desire to be unimpeded in one's actions (negative face).

The Model Person is designed to include more than just one person's own face-wants when they plan how to construct communication acts. The MP also incorporates the useful idea that a person's interlocutors also have the same kinds of face-wants themselves. Therefore the MP is useful for analyzing the construction of communication acts, because it supports careful examination of both the face-wants of the speaker and the face-wants of their interlocutors.

We can study the way people construct their dialogue for social effect by modeling human-human interaction as a dyad of MPs engaged in conversation. A dyad of MPs is a convenient model for exposing the conflicting social desires that people experience while interacting. The simple structure of an MP-MP dyad is sufficient to show that MPs' face-wants are interdependent — MPs depend on each other for the satisfaction of their face-wants. Brown and Levinson say that this simple interdependency is adequate to analyze all the subtlety of message construction for social effect observed in real human-human interaction.

People do not have direct control over the satisfaction of their face-wants. Face is also inconstant. Therefore, while people are interacting, they are also constantly attempting to maintain, enhance, and defend attacks against their stockpiles of positive and negative face. Face is a precious social commodity that is gained or lost during interactions but not manufactured in isolation.

THEORETICAL CONSTRUCT(S) about people (Brown and Levinson 1987):

P80. People purposefully plan the construction of their communication acts in particular ways that they intend to have specific social effects (see Theoretical Construct P76 (p. 40)).

P81. People make rational decisions when they plan the construction of messages to accomplish their social goals.

P82. People have two kinds of "face" that represent their social desires (face-wants): (1) to be approved of (positive face) and (2) to be unimpeded in actions (negative face). People understand that other people have the same face-wants as themselves.

[12] Brown and Levinson's Model Person serves a similar function as the Card et al. Model Human Processor (Card et al. 1983). However each model addresses a different topic of investigation: Brown and Levinson's Model Person allows us to study how people construct and use patterns of dialogue structure to influence their social environment, and the Card et al. Model Human Processor allows us to study how people accomplish physical tasks through the processes of perception, cognition, and motor control.

P83. People are interdependent for the satisfaction of face-wants. This interdependence originates from the fact that people are not able to independently satisfy their own face-wants but instead must depend on each other for face-rewards.

P84. While people interact, they constantly attempt to satisfy their social needs. They constantly apply their rational planning ability to enhance or defend their positive and negative face. There are two categories of people's continual social effort: (1) maintaining constant awareness of the influences of communication acts upon their face-wants and upon the face-wants of others and (2) dynamic adaptive rational planning of the structure of communication acts to exert appropriate social force (to satisfy both positive and negative face-wants. (Note: this new theoretical construct adds two more items to the growing list of things that people perform simultaneously while interacting.)

People sometimes design their communication acts in ways intended to attack each other's or their own face. Brown and Levinson call these attacks face-threatening acts (FTAs). People sometimes construct and execute FTAs as planned attacks upon face with which they intend to have some effect on social relationships. There are four categories of FTAs. These categories define to whom the threat is directed (the speaker or the listener) and the kind of face-threatened (positive or negative face) (Brown and Levinson 1987, p. 68). Table 2 illustrates these categories.

Table 2 — Face-threatening Actions by Who is Threatened

	speaker's face	**listener's face**
positive face	speaker degrades themself before listener	speaker degrades listener
negative face	speaker obligates themself to listener	speaker obligates listener to speaker

Categorization of face-threatening actions (FTAs) along two dimensions of threat: (1) who is being threatened and (2) what kind of face is being threatened.

Brown and Levinson say that interruption is a kind of FTA that intrinsically threatens both negative and positive face. Further, they define interruption as a blatant noncooperative action of discourse with which the speaker disruptively interrupts the listener's talk.

When the speaker interrupts the listener's talk, the speaker makes an FTA (face-threatening action) against the listener's negative face. By interrupting, the speaker implies that they do not intend to avoid impeding the listener's freedom of action. In fact, the interruption directly attacks the listener's freedom to continue talking. The speaker uses this same interruption FTA to also attack the listener's positive face. By interrupting, the speaker implies that they do not care about the listener's feelings, wants, needs, ... in effect, that the speaker does not want the listener's wants. Note, there are other kinds of dialogue behaviors (besides interruption) that intrinsically threaten both negative and positive face. These include: complaints, threats, strong expressions of emotion, and requests for personal information (Brown and Levinson 1987, pp. 65-67).

Interruption is an example of an FTA that threatens face by violating people's expected metadialogue regulation patterns for turn-taking. The theoretical constructs P53 (p. 33) to P57 (p. 33) of this report describe how people perform some communication acts solely to regulate the process of the interaction itself and do not convey meaning. Riley (1976) gave examples of three categories of behaviors that people use for metadialogue regulation — turn-taking signals, attention signals, and address signals. Brown and Levinson's (1987, p. 232) MP addresses the analysis of these behaviors as FTAs that act as violations of people's metadialogue regulation patterns of behavior. When people violate these regulation patterns, they impede their interlocutors' freedom to communicate (FTA of negative face), and they also imply that they do not care about their interlocutors' wants (FTA of negative face).

Face-threatening actions are not aberrations or infrequent outbursts of hostility — instead, they comprise a ubiquitous and essential part of normal human-human dialogue. People often need to disagree (threats to positive face) or arrange commitments (threats to negative face) between each other. The only way to accomplish these needs is to make FTAs. Most often, these disagreements or needed commitments are trivial, but people still must achieve them by making FTAs at each other. However, since the amount of "threat" in an FTA is relative to the significance of the disagreement (FTAs of positive face) or the needed commitment (FTAs of negative face), trivial FTAs carry trivial amounts of "threat." Brown and Levinson (1987, p. 13) claim that this theory of face and FTAs applies "universally" across all human languages and cultures.

Because FTAs are so common and because "threat" is a bad thing, regardless of the degree, people use many strategies to try to mitigate or hide the threats they make toward each other. These strategies are ways in which people plan the construction of their communication acts to provide redresses to those they threaten. Brown and Levinson (1987) call these strategies "politeness," and they present a useful taxonomy of politeness as a tool for investigating people's FTA behaviors.

It is useful to review their taxonomy here, with the exemplar of interruption as a FTA. I present examples of interruption for each category of politeness in Brown and Levinson's taxonomy (see Table 3 (p. 46)). This shows how people use different strategies to mitigate the negative effects of interruption.

Brown and Levinson's taxonomy of politeness has four basic categories of expression strategies: (1) bald-on-record, (2) positive politeness, (3) negative politeness, and (4) off record. The bald-on-record category describes the purposeful avoidance of any mitigating strategy (sometimes the most polite strategy is to be totally direct). The positive politeness category describes strategies people use to provide redress to threats to the listener's desire to be approved of (positive face). The speaker reduces the threat of their FTA by reducing the listener's cost of accepting the FTA and/or increasing the listener's ability to reject the FTA. For example, the speaker purposefully makes their own positive face obviously vulnerable. "Yes, I'm threatening your positive face, but as proof of my good intentions here, I make my own positive face vulnerable to counterthreats." Brown and Levinson say that positive politeness is the force behind familiar and joking behavior (see Fig. 5).

The negative politeness category describes strategies people employ to provide redress to threats to the listener's desire to be unimpeded in their actions (negative face). The speaker reduces the threat of their FTA by reducing the listener's cost of accepting the FTA and/or increasing the listener's ability to reject the FTA. For example, the speaker proposes reciprocity (an FTA to the speaker's negative face). "Yes, I'm threatening your negative face, but as proof of my good intentions here, I make my own negative face vulnerable to counterthreats." Brown and Levinson say that negative politeness is the force behind respectful behavior (see Fig. 6).

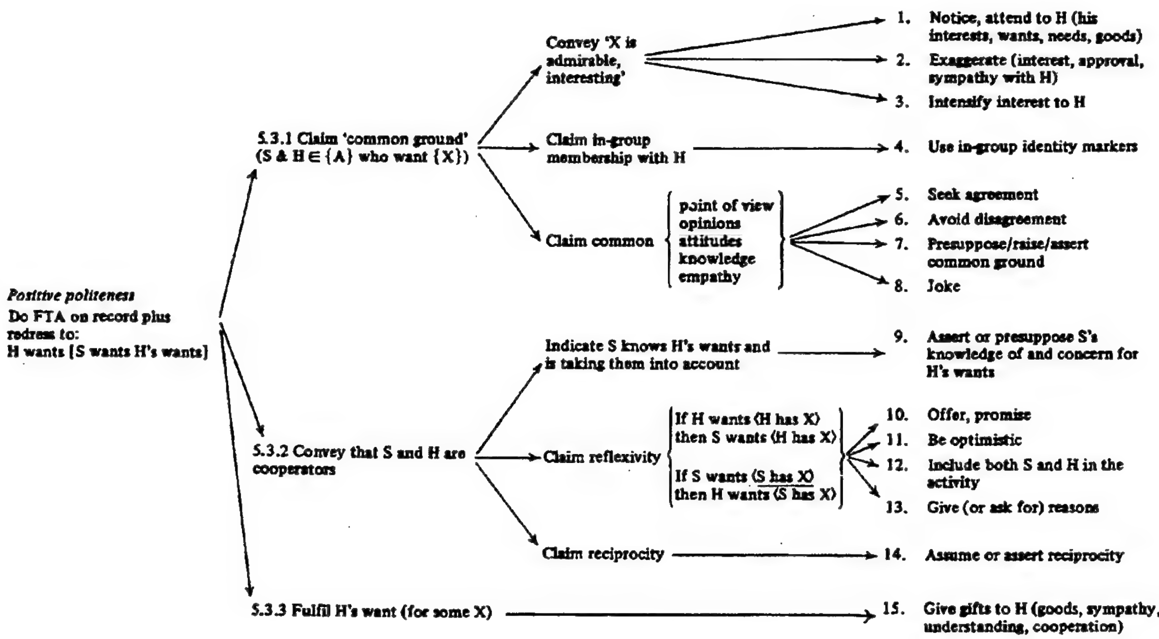

Fig. 5 — Positive politeness strategies. Reproduced from (Brown and Levinson 1987, p. 102).

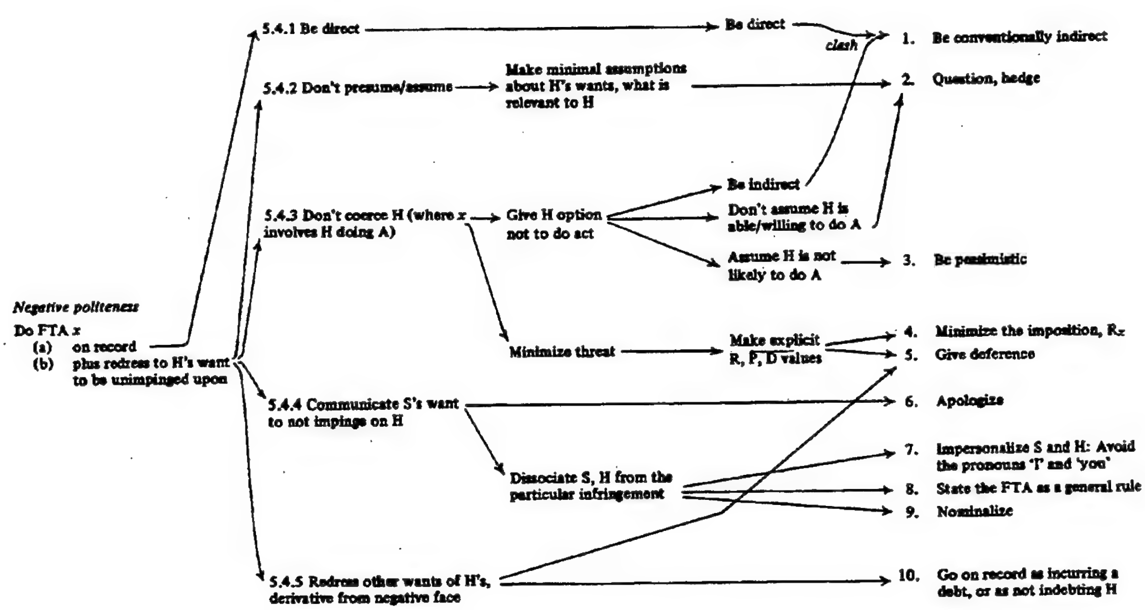

Fig. 6 — Negative politeness strategies. Reproduced from (Brown and Levinson 1987, p. 131).

The off-record politeness category describes strategies people use to create uncertainty about the existence of the FTA itself. This strategy embodies the idea that "people will feel less defensive if they are not

sure they are being threatened." Off-record politeness allows the speaker to avoid counterattack by allowing them to claim that no FTA was made. Off-record politeness also allows the listener to ignore threatening requests by allowing them to claim that no FTA was made. When people use off-record politeness strategies, they plan the construction of communication acts in ways that do not have one clear interpretation of their communicative intention. This allows both speaker and listener the potential to hide behind the ambiguity of language if needed. "Maybe I'm making a face-threatening act to you, and maybe I'm not. You can respond to my implied FTA if you choose to — or not." Fig. 7 shows the strategies for off-record politeness.

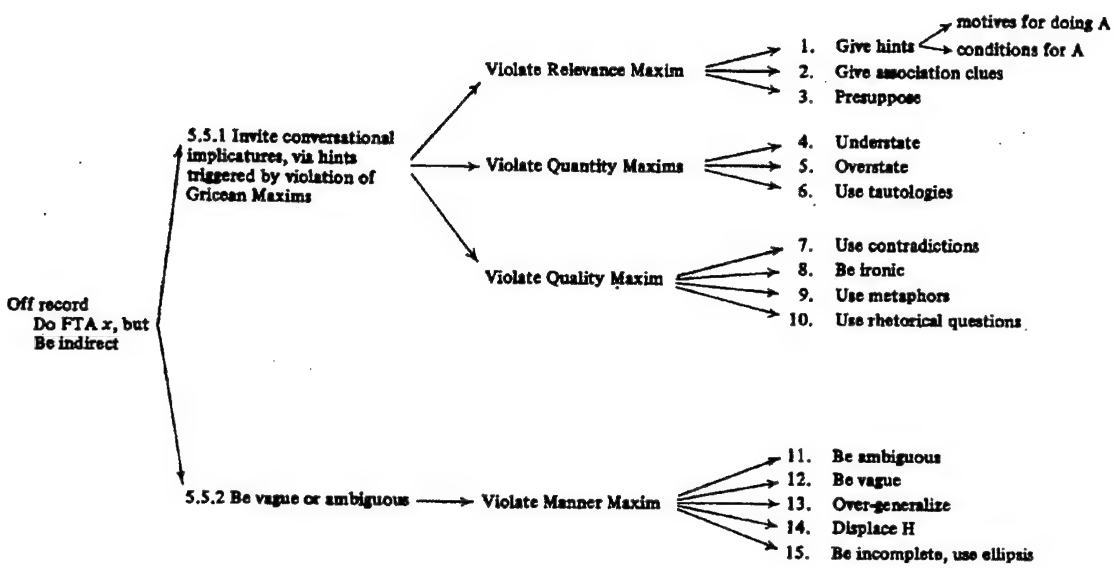

Fig. 7 — Off-record politeness strategies. Reproduced from (Brown and Levinson 1987, p. 214).

Table 3 is a taxonomy of polite interruption strategies. It employs Brown and Levinson's (1987, pp. 91-227) useful taxonomy of FTA (face-threatening action) threat-mitigation strategies (politeness) in the context of interruption. I have included examples of communication acts of interruption (interruption is an example of a kind of FTA that intrinsically threatens both positive and negative face) as examples for each strategy in the taxonomy.

Table 3 — Taxonomy of Polite Interruption

Category of Politeness	Example
I. Bald-on-record.	
[A] Be maximally efficient because other demands override any consideration of face-wants	"Hey, you are on fire!"

Table 3 — Taxonomy of Polite Interruption (Continued)

Category of Politeness	**Example**
[B] Be maximally efficient, because the listener is anxious to communicate with the speaker	"OK, the doctor will see you now."
II. Positive Politeness	
A. Claim common ground	
1. Notice, attend to the listener (their interests, wants, needs, or goods)	"Wow, your hair looks great that way! By the way, I want to talk to you about ...."
2. Exaggerate (interest, approval, sympathy with the listener)	"I had to interrupt you this moment; I thought I would die if I didn't get to talk to you."
3. Intensify interest to the listener	"Hey, your idea worked great! Let me tell you what happened ...."
4. Use in-group language or dialect	"Hey, pal, let's talk."
5. Seek agreement	"The Bulls did well last night. By the way, I want to talk to you about ...."
6. Avoid disagreement	"Excuse me. I agree with what you are saying, but ....."
7. Presuppose/raise/assert common ground	"I heard something that we need to talk about."
8. Joke	"Can I interrupt you from saving the world?"
B. Convey that speaker and listener are cooperators	
9. Assert or presuppose speaker's knowledge of and concern for the listener's wants	"I know you need to concentrate for several hours, so let me interrupt you now and leave you alone the rest of the day."
10. Offer, promise	"If you can give me a few minutes now, I'll try later to find a copy of that paper you want."
11. Be optimistic	[sit down opposite listener] "I've come to talk to you."
12. Include both the speaker and the listener in the activity	"Let's talk."
13. Give (or ask for) reasons	"Is there any reason I should not interrupt you now?"
14. Assume or assert reciprocity	"If you will let me interrupt you now, I will owe you one."

Table 3 — Taxonomy of Polite Interruption (Continued)

Category of Politeness	Example
C. Fulfill the listener's want for something	
15. Give gifts to the listener (goods, sympathy, understanding, or cooperation)	"Here's that paper you wanted. By the way, may I interrupt you."
III. Negative Politeness	
A. Be direct	
1. Be conventionally indirect	"Can you be interrupted?"
B. Don't presume/assume	
2. Question, hedge	"I need to interrupt you, if possible."
C. Don't coerce the listener	
3. Be pessimistic	"I don't suppose that I might interrupt you now."
4. Minimize the imposition	"I just need to interrupt you for a second."
5. Give deference	"Excuse me, Sir."
D. Communicate the speaker's want to not impinge on the listener	
6. Apologize	"Please forgive me for interrupting."
7. Impersonalize speaker and listener	"An interruption is necessary."
8. State the FTA as a general rule	[the speaker is wearing an usher's uniform] "Excuse me for interrupting, but it is this theater's policy that all patrons be asked to refrain from smoking."
9. Nominalize	"My interruption is regrettable."
E. Redress other wants of the listener	
10. Go on record as incurring a debt; or as not indebting the listener	"I would be very grateful if you would allow me to interrupt you now."
IV. Off record	
A. Invite conversational implicatures	
1. Give hints	[Clear throat loudly]
2. Give association clues	[Look at wrist watch in an exaggerated manner]
3. Presuppose	[Stare at the listener's face]

Table 3 — Taxonomy of Polite Interruption (Continued)

Category of Politeness	Example
4. Understate	[Stand perfectly still and stare at nothing]
5. Overstate	[Jump up and down and wave arms]
6. Use tautologies	[Talking out loud to self] "Time is money."
7. Use contradictions	[Speaker turns back to the listener exaggeratedly and fold arms]
8. Be ironic	[Talking out loud to self] "I know exactly what to do next."
9. Use metaphors	[Talking out loud to self] "I'm as confused as a hound dog at a tea party."
10. Use rhetorical questions	"I wonder if George [the listener] is busy right now."
B. Be vague or ambiguous: Violate Grice's Manner Maxim	
11. Be ambiguous	[Sigh loudly]
12. Be vague	"I'm here."
13. Overgeneralize	[Talking out loud to self] "Teams that don't coordinate often fail."
14. Displace the addressee	[Within hearing of the only expert on some topic who is busy working, interrupt someone else and ask them a question on the expert's topic.]
15. Be incomplete, use ellipsis	"I see you're ...."

THEORETICAL CONSTRUCT(S) about people (Brown and Levinson 1987):

P85. People frequently design their communication acts in ways intended to threaten each other's or their own "face." People do this because they must make face-threatening actions (FTAs) to accomplish every kind of disagreement or commitment with others (regardless of how trivial).

P86. People's face-threatening actions (FTAs) can be usefully categorized along two dimensions of threat: (1) who is being threatened (speaker or listener), and (2) what kind of face is being threatened (positive or negative).

P87. People use many strategies to mitigate the face-threats they make to each other in their FTAs (face-threatening actions). These strategies are planned attempts to construct the expression of communication acts (i.e., FTAs) in ways that inherently provide redresses to those threatened (Brown and Levinson call these strategies "politeness").

P88. People use four basic kinds of politeness strategies: bald-on-record (when efficiency is paramount); positive politeness (give redress to threats of positive face); negative politeness (give redress to threats of negative face); and off record (the speaker gives themself an easy way of avoiding retaliation and speaker gives listener an easy way of rejecting the FTA).

THEORETICAL CONSTRUCT(S) about interruption (Brown and Levinson 1987):

In3. Interruption is a kind of face-threatening action (FTA) that is intrinsically threatening to both negative and positive face. (Other intrinsic FTAs include: complaints, threats, strong expressions of emotion, and requests for personal information.)

Brown and Levinson's taxonomy of politeness is useful for researching human-human dialogue. It allows researchers to model and analyze the structure of people's communication acts and to infer people's intentions for social action. There are, however, interesting parts of human dialogue that are not included in this model and taxonomy. Two examples are: dialogue directed at oneself and other strategies for FTA construction besides mitigation of perceived threat.

People sometimes make communication acts that are clearly not intended to be perceived by anyone else. We can describe these communication acts as self-dialogue. Brown and Levinson say that people plan the structure of communication acts to accomplish their social intentions. What then, are people's social intentions when they communicate with themselves? Is it possible to analyze the structure of people's self-dialogue and find that they are trying to influence their own perceptions of themselves? If so, then the concept of "face" has another useful dimension — internal vs external face. Brown and Levinson address external face, but people may also have internal face — self-esteem (positive internal face) and morals (negative internal face).

Brown and Levinson's interactional sociolinguistics theory is limited to addressing people's politeness strategies. Other authors address different human social motivations that influence people's construction of FTAs. West (1982) reports on research about how people construct their communication acts in order to gain dominance over coworkers in an office environment. It may be useful to follow Brown and Levinson's method and construct probable underlying social motivations that people employ to acquire dominance — a taxonomy of dominance strategies. Such a taxonomy would be another essential tool for performing general research into interactional sociolinguistics.

2.12 Simultaneous Speech in Linguistics

Domain Specific Definition of Interruption: a disruptive type of simultaneous speech.

When people interact, sometimes they talk at the same time (linguists describe this as "simultaneous speech"). Simultaneous speech can be problematic, because people are not good at comprehending more than one spoken message at a time (Pashler 1993; Schneider and Detweiler 1988). Most of the time people speak one at a time and avoid the problems of simultaneous speech. Sacks, Schegloff, and Jefferson (Sacks et al. 1978) propose a theoretical model for investigating how people coordinate turn-taking in conversations. Sacks et al. say that people engage in turn-taking behaviors as a necessary way of sharing the scarce verbal communication channel. "For socially organized activities, the presence of 'turns' suggests an economy, with turns for something being valued, and with means for allocating them affecting their relative distribution, as they do in economies" (Sacks et al. 1978, pp. 7-8). People usually act economically and coordinate turn-taking in order to most efficiently use the scarce verbal channel. Nevertheless, people also spice their dialogue with frequent small bouts of simultaneous speech — why?

People frequently do not engage in turn-taking; this results in more than one person talking at the same time (simultaneous speech). Interruption is a kind simultaneous speech, so it is useful for this discussion to examine the theory relevant to simultaneous speech. The current literature says it is useful to categorize simultaneous speech into three classes: (1) dialogue facilitation; (2) unintentional coordination errors in turn-taking; and (3) direct confrontation for control of the floor.

Back-channeling is a useful example of simultaneous speech for dialogue facilitation (Brennan 1990, p. 395; McCarthy and Monk 1994, p. 42; Pérez-Quiñones 1996, p. 114). Listeners usually provide feedback to their speaker of the success or failure of the communication processes. Listeners initiate brief simultaneous speech acts (or other kinds of brief communication acts) during the speaker's communication turn, e.g., acknowledging eye contacts, head nods, and "um humm's." These kinds of simultaneous speech tell the speaker whether the listeners are attending, hearing, and/or understanding the speaker's messages. (Note: these three states of listener understanding come from Clark's "States of Understanding" for grounding (Clark and Schaefer 1989; Pérez-Quiñones 1996, p. 89).)

Human dialogue is not error-free. Dialogue can breakdown in a myriad of ways. The fragility of the dialogue processes has created the need for some metacommunication acts, like back-channeling, for grounding. The regulation of turn-taking is yet another dialogue process that is itself susceptible to error. People sometimes begin talking simultaneously without intending to do so. When errors happen, people try to repair their dialogue. Sacks et al. (1978, pp. 39-40) report on such dialogue repair behaviors.

The third category of simultaneous speech describes interruption as a purposeful attempt to control the floor. There are different reasons that motivate people to interrupt for control — sometimes people intend to aid the speaker, and sometimes people intend to subvert the speaker. For example, Brown and Levinson (1987) (see theoretical construct P88 (p. 50)) acknowledge that sometimes people need to interrupt each other for cooperative reasons. If the speaker is about to tread on a snake, the listener can interrupt and yell, "Watch out!" (bald-on-record for maximal efficiency). However, people also sometimes use interruption to subvert the speaker. West (1982) describes the human behavior of using interruption with the intention of establishing or strengthening a dominance relationship with the speaker and/or other listeners. West calls occurrences of these subversive simultaneous communication acts "deep interruptions."

West (1982) says that people react to being interrupted in strategic ways intended to minimize the subversive effects of the interruption. There are two basic categories of reactive strategies: (1) passively allow the interruption but draw attention to the turn-taking violation, and (2) actively fight off the interruption. If the speaker is interrupted, they can mark or draw attention to the interruption as an attack on their right to speak. They can do this by dropping out of the conversation suddenly, leaving a partially finished statement unfinished.

An interrupted speaker may instead try to directly fight off the subversive effects of an interruption by continuing to talk simultaneously throughout the interruption. West says that speakers sometimes stretch or repeat portions of their speech ad infinitum to continue talking and eclipse an interruption. Speakers may instead pretend to ignore the violation of their turn and continue without pause and finish their turn normally, i.e., just keep talking as if the interruption were not happening. Either of these fighting strategies, if executed successfully, seems to be effective in negating the subversive effects of interruption (West 1982).

THEORETICAL CONSTRUCT(S) about people (West 1982):

P89. People sometimes speak simultaneously ("simultaneous speech").

P90. Most speech communication is not simultaneous because of the problems humans experience in perceiving multiple verbal messages at the same time. People usually employ a metacommunication regulation process of turn-taking to avoid the problems of simultaneous speech.

P91. Although simultaneous speech does not constitute a majority of people's speech communication, people do frequently spice their dialogue with simultaneous speech. There are three classes of simultaneous speech: (1) dialogue facilitation (for example, back-channeling); (2) unintentional coordination errors in turn-taking (for example, false starts); and (3) direct confrontation for control of the floor (for example, bald-on-record politeness or subversive attempts to establish dominance relationships).

P92. People possess defensive behavior strategies for negating the possible subversive effects of interruption. These strategies include: marking the interruption as a violation of one's right to speak; eclipsing the interruption; and ignoring the interruption.

2.13 Language Use in Linguistics

Domain Specific Definition of Interruption: a proposal for an entry into or exit out of a joint activity.

It is important to consider the interruption of people by the use of language. Clark (1996) in his book titled *Using Language*, presents an important and useful theory of human language. Clark proposes that for a theory of language to be useful, it must support the research of language within its complex context of use. Some other authors have tried to circumvent the complexities of language by asserting that language can be isolated from its context, but this is ineffectual. Language can not be separated from its context of use, i.e., who is using it (participants); what they are doing (joint activities); where they are using it (physical, psychological, and social contexts); why they are using it (joint purposes), and how they are using it (communication of meaning and coordination of the communication process itself).

People do things together. Clark says that the activities people perform together become more than the sum of individual behaviors. He calls these multiperson activities "joint activities," and he says that joint activities are composed of "joint actions."

> "A joint action is one that is carried out by an ensemble of people acting in coordination with each other. As simple examples, think of two people waltzing, paddling a canoe, playing a piano duet, or making love. When Fred Astaire and Ginger Rogers waltz, they each move around the ballroom in a special way. But waltzing is different from the sum of their individual actions — imagine Astaire and Rogers doing the same steps but in separate rooms or at separate times. Waltzing is the joint action that emerges as Astaire and Rogers do their individual steps in coordination, as a couple. Doing things with language is likewise different from the sum of a speaker speaking and a listener listening. It is the joint action that emerges when speakers and listeners (or writers and readers) perform their individual actions in coordination, as ensembles" (Clark 1996, p. 3).

Joint activities expose joint purposes. People use language to communicate and coordinate the accomplishment of their joint activity. However, the language use itself is only a means to an end. The relationship between language and joint activities can be illustrated with the metaphor of the relationship between a car and a person's need to get from point A to point B. In general, people drive cars to get somewhere — they do not just drive their cars around and around aimlessly. (Even "Sunday drivers" out for a rid, have the aim of seeing particular things, and they guide their cars purposefully toward some scenic road or other.)

In a similar way, people do not just make communicative expressions without purpose. They talk, or gesture, or ..., as a means of accomplishing some joint purpose (Clark 1996).

Joint activities always include some amount of language use (language use is itself a kind of joint activity). This is why we must observe language within its context of use — people's language use is directly tied to the joint activities they are attempting.

> "Just as language use arises in joint activities, these [joint activities] are impossible without using language. Two or more people cannot carry out a joint activity without communicating, and that requires language use in its broadest sense. Yet whenever people use language, they are taking joint actions. Language use and joint activity are inseparable. The conclusion once again, is that we cannot understand one without the other. We must take what I call an action approach to language use, which has distinct advantages over the more traditional product approach" (Clark 1996, p. 29).

THEORETICAL CONSTRUCT(S) about people (Clark 1996):

P93. People engage in "joint activities" with other people. The performance of joint activities is more than the sum of the individual behaviors of the participants. Individual behaviors become interwoven into a fabric of coordination created by the participants.

P94. People coordinate joint activities with language use. Since joint activities require coordination, participants must use language to perform every kind of joint activity.

P95. People perform joint activities to satisfy their joint projects. Joint projects are joint goals that people agree on. The language use that people exhibit while performing joint activities is only a means to their joint project ends — the language use itself is not meaningful in isolation.

THEORETICAL CONSTRUCT(S) about context (Clark 1996):

C2. Language cannot be separated from its context of use (the participants; their joint activities; the physical, psychological, and social contexts; their joint purposes; and communication of meaning and coordination of the communication process itself).

This theory of language use and joint activities is useful for researching the topic of this report — interruption of people by computers. Clark says that language use is itself a kind of joint action. He also says that joint activities have boundaries (entry, body, and exit) and that all entries and exits have to be engineered separately for each joint action (Clark 1996, p. 37). We can, therefore, define interruption as the occurrence of a person making communication acts with the intention of initiating the entrance into some joint activity.

To use Clark's theory, we must understand how it explains three aspects of joint activities relative to interruption: (1) the structure and dimensions of variation in joint activities; (2) the communicative mechanisms that people use to propose entrance into joint activities; and (3) coordination between participants of the entrance into joint activities.

2.13.1 The Structure and Dimension of Variation of Joint Activities

Clark (1996, p. 37) says that joint activities have flexible and dynamic structures: two or more joint activities can be performed simultaneously by the same participants; a single joint activity can be performed intermittently; joint activities may be divided, expanded, and/or contracted dynamically to accommodate changes to the group of participants (people can enter and exit from a joint activity already in progress). The support of simultaneity and intermittence of performance are particularly useful for researching interruption of a person interacting with a system of multiple intelligent software agents.

Another property of the structure of joint activities is that they are nested. "A joint activity ordinarily emerges as a hierarchy of joint actions or joint activities" (Clark 1996, p. 38). This idea is similar to the application of GOMS analysis by the hierarchical decomposition of goals into subgoals (Card et al. 1983). A high-level joint activity can be analyzed into its component low-level joint activities. For example, two people are in a store — a customer and a clerk. They attempt to accomplish the high-level joint activity of a business transaction. It is useful to decompose this joint activity into its component joint activities. These lower-level joint activities include: (1) both participants enter into a business transaction; (2) both participants settle the nature of the transaction (which products the customer will purchase); (3) both participants settle on the total cost of the transaction; (4) both participants make the exchange; and (5) both participants agree to end joint activity.

Clark enumerates dimensions of variability inherent in different types of joint activities. These dimensions are: scriptedness, formality, verbalness, cooperativeness, and governance. Scriptedness is the degree of prearrangement of specific behaviors (for example, participants in a marriage ceremony have preagreed on specific sequences of joint actions). Formality is the amount of agreed-upon behavioral protocols (for example, participants in a presidential debate are constrained by several preagreed upon protocols). Verbalness is the degree to which participants use speech in the joint activity (for example, participants in a fencing match use very little speech). Cooperativeness is the degree to which participants want the same outcome of the joint activity (for example, participants in a chess match want different outcomes). Governance is the degree to which control of the joint activity is shared among the participants (for example, the examiner has more control than the applicant in directing the joint activity of taking the driving test with the Department of Motor Vehicles) (Clark 1996, p. 30).

Clark presents a summary of the elements that affect people's performance of joint activities, as seen in Table 4. I have refrained from a lengthy discussion of all of these structural elements — I think the following table is sufficient here.

THEORETICAL CONSTRUCT(S) about people (Clark 1996):

P96. People's language use is itself a kind of joint activity.

P97. People propose entrance to and exit from joint activities to other people. (We call this interruption.)

P98. People's joint activities have flexible and dynamic structures. Joint activities support the following kinds of flexibility: they can be performed simultaneously or intermittently; they can be divided, expanded, and/or contracted dynamically to accommodate changes to the group of participants; and they can be (and usually are) nested.

P99. There are dimensions of variability that affect people's performance of joint activities: scriptedness, formality, verbalness, cooperativeness, and governance.

Table 4 — The Structure of Joint Activities

element	explanation
Participants	A joint activity is carried out by two or more participants.
Activity roles	The participants in a joint activity assume public roles that help determine their division of labor.
Public goals	The participants in a joint activity try to establish and achieve joint public goals.
Private goals	The participants in a joint activity may try individually to achieve private goals.
Hierarchies	A joint activity ordinarily emerges as a hierarchy of joint actions or joint activities.
Procedures	The participants in a joint activity may exploit both conventional and nonconventional procedures.
Boundaries	A successful joint activity has an entry and exit jointly engineered by the participants.
Dynamics	Joint activities may be simultaneous or intermittent, and the membership of its group of participants may dynamically expand, contract, or divide.

Clark's general claims about the structure of joint activities (Clark 1996, pp. 38-39).

THEORETICAL CONSTRUCT(S) about context (Clark 1996):

C3. The linguistic context affects joint activities: participants, activity roles, public goals, private goals, hierarchies, procedures, boundaries, dynamics.

One of Clark's joint activity element structures is "boundaries." He says that people's joint activities have boundaries in time. Clark identifies stages of performance of joint activities: "entry," "body" and "exit." Entry is the stage where the participants of a joint activity transition from not being involved in the joint activity to being involved in the joint activity, i.e., the transition of individual people into joint activity participants. Body is the stage where participants perform the joint activity. Exit is the stage where participants of the joint activity transition from being involved in the joint activity to being not involved, i.e., the transition of participants of the joint activity back into individual people.

Clark says that transitions into and out of joint activities (entries and exits) are critical. "Entries and exits have to be engineered for each joint action separately. That makes entries and exits especially important features of joint activities" (Clark 1996, p. 37). One person (the speaker) proposes entrance into a joint project to another person (the addressee), who takes it up.

2.13.2 The Communicative Mechanisms that People Employ to Propose Entrance into Joint Activities

I use Clark's theory of language to define interruption as "the occurrence of a person proposing entrance to, or exit from, a joint activity to another person (or group of people)." This is directly useful to the subject of this report — user-interruption in HCI. For HCI, this definition can be rewritten as "the occurrence of a computer proposing entrance to, or exit from, a joint activity to its human user(s)."

How do people make these interruptions? People propose entries and exits by using language to communicate their meanings to each other. Clark presents a theory of signals to support investigation of the basic process of communication meaning between people. What is most interesting is how people use the structure of joint activities and signaling to engineer joint activities. However, it is essential to discuss signaling theory before discussing how people actually coordinate entrance and exits of joint activities.

Clark (1996, p. 160) defines signals as "the presentation of a sign by one person to mean something for another." A signal is a process of conveying meaning between people. People deliberately choose a signaling class to form the expression of the communication acts they make. Each of the three signaling classes is composed of: (1) a kind of sign, (2) a method of signaling, and (3) a targeted cognitive process of sign interpretation within the listener.

This concept of signal is not limited to static representations of meaning but encompasses the total process of conveying meaning between participants. People signal other people — the speaker creates and expresses some composition of signs with the intention of conveying a particular meaning, and the audience receives those signs and interprets the meaning. Signs comprise signals and affect the audience by creating in their mind(s) particular ideas. Clark's signals are similar to the concepts of communication acts employed by Riley (1976) in Theoretical Constructs P50 (p. 31) and P51 (p. 31). Communication acts make clear distinctions between meaning, the expression of communicative behaviors, and the channels of conveyance. Clark's signals promote similar distinctions between meaning and its expression.

Signs evoke meaning in their human receivers. Clark categorizes signs into three classes: icons, indexes, and symbols. Clark (1996) says these categories reflect the three different ways that people are able to interpret meaning. Each class of sign expressed evokes a different kind of cognitive recognition process within its audience. Audiences interpret each class of sign by using different memory resources to construct meaning from the sign behaviors they perceive from speakers. Icon signs evoke perceptual memories. Index signs evoke memories of physical or temporal relationships. Symbol signs evoke memories of learned rules of association.

Clark's methods of signaling (Table 5) align the meaning a person intends to communicate with the particular cognitive process the listener will use to understand that meaning. Signaling processes and signs describe different ways people understand things, and the methods of signaling describe people's choice of communication expression to convey that meaning. The three classes of signaling methods are: demonstrate, indicate, and describe. These methods are each exclusively associated with a particular class of sign and sign process: people demonstrate with icon signs that evoke perceptual memories in their communication partners; people indicate with index signs that evoke memories of physical association in their communication partners; and people describe with symbol signs that evoke memories of learned rules of association

Clark emphasizes the classes of signaling methods as easy means of discussing the different ways people signal each other. This approach is useful because each class of signaling method assumes a particular class of signal and a particular class of cognitive process for interpretation. For example, the describing-as method of signaling is always accompanied by the creation and expression of symbol signs which the audience interprets by using their memories of rules of association to constructivistly recognize the meaning conveyed. Conventional English language words like "whale," "opera" and "sing" are clear illustrative examples of symbols. Speakers use symbols when they describe things to their audience. Obviously, speakers often use symbols by uttering them as spoken words. However, there are other interesting ways of using symbols in description. Some physical gestures are expressions of symbols — there are a set of gestures that both speaker and audience have learned to associate meaning by rule. Clark calls these emblems. Examples are: the head nodding gesture means "yes" and the shoulder shrugging gesture means

"I don't know." There are also auditory emblems that people have learned to associate nonword sounds with particular meanings, e.g., clapping means "I approve." Clark also describes a kind of gesturing he calls junctions, in which participants express the symbolic gesture simultaneously, e.g., shaking hands. (Clark 1996, pp. 161-164).

Table 5 — Signaling Classes

	Description	**Indication**	**Demonstration**
Kinds of signs	symbol	index	icon
Cognitive processes of sign interpretation	learned rule association	physical or temporal association	perceptual similarity association
Methods of signaling	describing-as	indicating	demonstrating

Signal classes based on Clark's theory of signaling (Clark 1996, pp. 155-188). People create signals as trios of three interrelated structures: signs, cognitive processes within their audience, and methods of signaling.

The indicating method of signaling is always accompanied by index signals that require the audience to apply their memories of physical or temporal associations. People signal for indication with their audience when they intend to create indices for the objects (including people), events, or states that they want to refer to. A person pointing their index finger at some object is a simple example of indication. Indexing has five requirements: (1) the index expressed so that all participants focus attention on it; (2) the index locates some object, event, or state in space and time; (3) the index presents a physical and/or temporal association; (4) the index is accompanied by a description that identifies a particular instance of the object; and (5) the speaker presumes that their audience can satisfy requirements 1-4 based on their current common ground (Clark 1996, pp. 164-172).

The demonstrating method of signaling is always accompanied by icon signals that require the audience to apply their memories of perceptual similarity. Clark (1996, p. 174) says, "the point of demonstrating is to enable addressees to experience selective parts of what it would be like to perceive the thing directly." Demonstration works because people are able to add an imaginary layer to their conversations. This imaginary layer affords people the opportunity to imagine that icons are the objects they represent. Clark says there are several ways of expressing demonstrations, including iconic gestures. Component gestures are selective depictions embedded within larger utterances. Concurrent gestures can be icons that a person makes while they utter something. Facial gestures often demonstrate what the speaker's face would look like if they were experiencing some meaningful reaction. Vocal gestures are icons people use to demonstrate meaning by making selectively depictive sounds (Clark 1996, p. 172-183).

Clark provides a classification table (Table 6) of examples of different, easily recognized communicative behaviors and where they fall within his signaling categorization theory (Clark 1996, p. 188).

Clark (1996) says that it is useful to describe people's signaling by clearly distinguishing the kind of signal, the instrument they use, and the depictive action they take. Table 7 shows how people can use all classes of signaling and all of the instruments of their bodies for interruption, i.e., to propose entrance into a joint project to another person(s). [Note: "<I>" stands for instrument and "<O>" for object.]

Table 6 — Signaling Methods and Instruments of Expression

	Method of Signaling		
Instrument	**Describing-as**	**Indication**	**Demonstrating**
voice	words, sentences, vocal emblems	vocal locating of "I" "here" "now"	intonation, tone of voice, onomatopoeia
hands, arms	emblems, junctions	pointing, beats	iconic hand gestures
face	facial emblems	directing face	facial gestures, smiles
eyes	winks, rolling eyes	eye contact, eye gaze	widened eyes
body	junctions	directing body	iconic body gestures

Examples of different kinds of communicative behaviors, and where they fit into Clark's signaling theory classification. Reproduced from (Clark 1996, p. 188).

Table 7 — Signaling for Interruption

Instrument	Depictive action	Example
Description		
voice	utter <O> with <I>	"ugh um" {clearing the throat loudly is a verbal emblem people have learned to mean "I need to interrupt you now"}
voice	utter <O> with <I>	"I need to interrupt you now" {words are symbols}
hands	gesture <O> with <I>'s	"[make the football game time-out signal by bringing the two hands together into a "T" shape]" {this is an emblem that people have learned to mean "I request an interruption"}
finger	gesture <O> with <I>	"[make the "shhhh" signal by placing an index finger vertically across closed mouth]" {this is an emblem that people have learned to mean "I request you to stop (or interrupt) your speaking"
Indication		
eyes	gazing at <O> with <I>	"[turn eyes to gaze at someone] Excuse me" {the eye gaze indicates who I want to interrupt}
finger	pointing at <O> with <I>	"[point at someone] Excuse me" {the finger pointing indicates who I want to interrupt}
arm	raising <I> in the visual field of <O>	"[a student raises their arm upwards toward the instructor during a lecture]" {the student indicates themself as the proposer of an interruption}

Table 7 — Signaling for Interruption (Continued)

Instrument	Depictive action	Example
voice	identifying <O> with <I>	"I need to interrupt you now" {this utterance indicates "I," "you," and "now"; the rest of the utterance is describing-as}
Demonstration		
fingers	forming <I>'s into <O>'s shape	"[I put my fingers to my mouth as if I were whistling loudly]" {I interrupt you by demonstrating a loud whistle (whistle not actually made)}
voice	mimicking <O> with <I>	"Your mom said, 'get William off the telephone' [impersonation of mother's voice]" {I interrupt William with a demonstration of his mother interrupting him.}
arm	miming <O> with <I>	(you are across the room from me) "[I use one arm to demonstrate a pulling motion]" {I mean that I want to interrupt you from whatever you are doing and draw you to me}
hand	forming <I> into <O>'s shape	(I want to interrupt you during your telephone conversation) "[I use my hand to make a cutting gesture between you and your telephone]" {I demonstrate cutting your phone cord so I can interrupt your conversation}

Clark says that people usually use composite signals in which they mix all three kinds of signals. The reader may ask, "If people actually signal with composite signals, why is it useful to employ Clark's signaling theory which classifies signals into three separate categories?" My answer is that Clark's signaling theory allows us to analyze people's communicative behaviors in terms of their use of different kinds of cognitive resources. Even though a person signals with a mix of different signaling types, we can analyze how the speaker and their audience are using different cognitive resources to accomplish that signal — perceptual memories for icons, physical or temporal association memories for indexes, and rule association memories for symbols.

It is useful to show the utility of Clark's signaling theory by employing it to analyze an example of interruption (a person proposing entrance into a joint project with another person). Thomas interrupts Miranda while she is talking on the telephone: [Thomas walks over near Miranda] [he turns his head and body toward her] [he fixes his eye gaze on her] [he reaches out his hand and makes a cutting gesture between her and the telephone] (while making his hand gesture, he utters) "Excuse me Miranda, I need to interrupt you now please, it's urgent."

Thomas's behaviors of moving his body closer to Miranda, orienting his body, head, and eye gaze toward her are all indication signals. These behaviors draw Miranda's attention to Thomas, they locate him in physical space; he specifies himself as a particular person making an interruption (instead of just an abstract person (description)); and because of their common ground, he presumes that Miranda can understand his meaning. Thomas also uses utterance for indication signals. He indicates himself as the proposer of a new joint project with the word "I"; he indicates Miranda as the recipient with the words "Miranda" and "you"; and he indicates the time of his proposal with the word "now." We can analyze all these indication signaling in terms of how Thomas and Miranda use their cognitive memories of physical and

temporal associations to accomplish the conveyance of index signs. Thomas's behavior of hand gesturing a cutting motion between Miranda and her phone is a demonstration signal. Thomas provides Miranda with an imaginary experience of severing her telephone conversation. We can analyze how Thomas and Miranda use their cognitive, perceptual, and similarity memories to accomplish the conveyance of this icon sign. Thomas's behavior of uttering words are description signals. His uttered sentence conveys symbol signs that Miranda must interpret. Thomas uses symbol signs to describe that he "needs" to "interrupt" her, "please." We can analyze how Thomas and Miranda use their cognitive rule association memories to accomplish the conveyance of these symbols signs.

THEORETICAL CONSTRUCT(S) about people (Clark 1996):

P100. People's joint activities are bounded in time into entrance, body, and exit; and people must engineer each one of these stages of joint activities. (Note: theoretical construct P97 (p. 54) says that we can define interruption as the occurrence of one person proposing entrance to or exit from joint activities to other people.

P101. People convey meaning to each other by signaling. A signal is the means by which a speaker creates and expresses signs which cause their audience to interpret some intended meaning.

P102. People use three kinds of signals: description, indication, demonstration. These categories correspond to the three different ways that people are able to cognitively process meaning. Each kind of signal has (1) its own kind of signs of which it is composed, (2) its own cognitive process of interpretation in the audience, and (3) its own method of signaling.

P103. People convey meaning with description signals by referring to conventional systems of meaning — like words — that both speaker and audience have learned to associate by rule. Description (1) creates symbol signs, (2) requires the audience to use their memories of rules by association for interpretation, and (3) is expressed by the speaker with the describing-as method of signaling.

P104. People convey meaning with indication signals to identify or mark an object, event, or state for future reference. Indication (1) creates index signs, (2) requires the audience to use their memories of physical or temporal association for interpretation, and (3) is expressed by the speaker with the indicating method of signaling.

P105. People convey meaning with demonstration signals by enabling their audience to experience selective parts of what it would be like to perceive directly the original. Demonstration (1) creates icon signs, (2) requires the audience to use their memories of perceptual similarity for interpretation, and (3) is expressed by the speaker with the demonstrating method of signaling.

P106. People usually use composite signals in which they mix all three kinds of signals.

People create complex heterogeneous signals (theoretical construct P106 (p. 60)), but how do they decide which kinds of signals to combine? Clark says people choose the composition of their signals based on the dynamics of the pertinent joint activities. He proposes three dynamic factors of interaction that affect how people choose different kinds of signals to combine purpose, availability, and effort (Clark 1996, pp. 186-187). First, joint projects have purposes that may suggest or even require specific types of signals.

Clark says, "in so far as describing-as, indicating, and demonstrating serve different purposes, speakers' choices of composite must conform to their purposes" (Clark 1996, p. 187). The second factor — availability — affects peoples choices because some contexts do not allow some kinds of signals. For example, when people interact over the telephone, they do not have the option to choose many kinds of gestural indexing signals that depend on people's ability to see each other. The third factor — effort — reveals that different kinds of signaling afford the conveyance of different kinds of information. It may be possible to convey a single meaning in different ways, i.e., with alternate kinds of signaling. However, each alternate signaling type requires a different amount of effort to accomplish. For example, if I wanted to tell you how to tie a shoe, I might be able to do it with the describe-as method of signaling (I describe how to hold the two ends of the laces, and then how to wrap one around the other, and then ...), but I could accomplish it much easier by the demonstration method of signaling (I demonstrate by tying my shoe).

THEORETICAL CONSTRUCT(S) about people (Clark 1996):

> **P107.** People create complex heterogeneous signals (theoretical construct P106 (p. 60)) by selecting and intermixing different kinds of signals that best convey meaning in their dynamic joint activities. Three factors of joint activities affect people's selection of signal types: purpose, availability, and effort.

2.13.3 Coordination Between Participants of the Entrance into Joint Activities

People can construct appropriate signals to convey meaning within dynamically changing joint activities. The meaning people convey with signals allows them to accomplish their joint purposes. The most obvious kind of information people convey to each other is related to the subject of their joint activity, however people must also perform a significant amount of signaling just to coordinate the joint activity itself. Clark says that coordination is the key to joint activities. "What makes an action a joint one, ultimately, is the coordination of individual actions by two or more people. There is a coordination of both content, what the participants intend to do, and processes, the physical and mental systems they recruit in carrying out those intentions" (Clark 1996, p. 59).

The previous two subsections of this report presented the background information necessary for a discussion of the coordination of joint projects and its relevancy to interruption, i.e., (1) the structure of joint activities and (2) how people signal each other. Interruption is defined here as a proposal for entry into a joint activity; therefore, it is important to understand how Clark's theory addresses the coordination of such proposals and entries.

Clark (1996, p. 191) says, "a joint project is a joint action projected by one of its participants and taken up by the others." There are several aspects of a proposed joint project that must be coordinated between the proposer and their intended collaborators. Participants must coordinate on:

(1) agreement: whether or not there will be a joint project;
(2) who: the group of participants;
(3) what: the content of joint activity and the roles of participants;
(4) where: the location;
(5) when: times of state transitions (entry time, body time, and exit time);
(6) why: joint purpose; and
(7) how: state changes, and signaling channels (e.g. telephone, e-mail, or face-to-face).

People are not always successful at accomplishing the joint projects they desire. Clark (1996, p. 203) says there are four factors that specifically affect people's ability to coordinate entrance into joint projects.

All of these factors must be successfully coordinated for people to commit themselves to enter into a joint activity. These factors are: identification, ability, willingness, and mutual belief. Since these four factors are requirements of entrance into joint projects, they are also the requirements for successful interruption. I use Clark's labeling convention of *"A"* for the person proposing a joint project, *"B"* for the person or people receiving the proposition, and *"r"* for the joint project itself.

(1) Identification: both *A* and *B* must coordinate a joint understanding of the nature of *r*. This understanding comes from coordinating the seven aspects of a proposed joint project, as described in the preceding paragraph (agreement, who, what, where, when, why, and how).
(2) Ability: both *A* and *B* must be able to fulfill their roles in *r*.
(3) Willingness: both *A* and *B* must be willing to fulfill their roles in *r*.
(4) Mutual belief: *A* and *B* must each believe that they both have successfully coordinated all three factors 1, 2, 3 and that they have now coordinated factor 4.

An illustrative example is useful here: Eric proposes entry into a joint activity to Barbara. Initially, Barbara is working alone on her computer; Eric walks into her office and interrupts.

Eric: "Barbara, excuse me."
Barbara: "Just a moment." [she keeps working for 10 seconds, then stops, and turns around], "Yes?".

Eric proposes a joint activity — that he and Barbara enter into a conversation (factor 1). Eric also shows that he is able and willing to do his part (factors 2 and 3). Barbara's response, "just a moment," conveys that she has identified Eric's purpose (factor 1) and that she will be willing and able to enter the proposed joint activity in a few seconds. Barbara continues to work for 10 more seconds, and then stops and turns around, and says, "Yes." At this point both Eric and Barbara accomplish factor 4. They enter the joint activity.

Barbara accepted Eric's proposal for entrance into a joint activity, but she altered one aspect of his original proposal. When Eric said, "Barbara, excuse me," Eric meant that he and she enter his joint activity "right now." Barbara altered Eric's "when" aspect of Eric's original proposal.

People have alternative responses for answering propositions for entrance into a joint activities. Clark (1996, pp. 203-205) has identified four possible responses: take-up with full compliance; take-up with alteration; decline; and withdraw (see also Clark's discussion of the "Emergence of Conversations" and "Opening Sections" (Clark 1996, pp. 331-334)).

Table 8 discusses these alternative responses to entry propositions. To illustrate each possible response, I provide an example variant of Barbara's response to Eric's proposal (Clark 1996, pp. 203-205, pp. 331-334).

There is a subtle difference between Clark's "decline" and "withdraw." This reflects the idea that people in U.S. English culture maintain a subtle informal agreement not to ignore each other. This cultural agreement implies that once a person makes a proposition for a joint activity to other people, these recipients may already feel some commitment to at least decline the proposal. Clark has included the special case of "withdraw" to describe a kind of response in which people not only decline the proposed joint project but also decline their cultural contract to not ignore proposals in general.

Table 8 — Possible Responses to a Proposal for Entry into a Joint Activity

response type	definition	example
take-up with full compliance	recipient complies fully with entrance into joint project exactly as proposed	"[Barbara immediately stops whatever she is doing and turns around], yes?"
take-up with alteration	recipient agrees to enter into an altered version of the original proposal [recipient declines original proposal and counter-proposes with an altered version of the original]	Barbara says, "Just a moment. [she keeps working for 10 seconds, then stops, and turns around] Yes?"
decline	recipient declines to enter into the proposed joint project, because they are either unable or unwilling to comply	"[Barbara does not stop her work or turn around], sorry, I'm too busy right now"
withdraw	recipient withdraws entirely by responding with something completely unrelated	"[Barbara ignores the proposal: she does not stop her work, or turn around, or even respond]"

The four possible responses to a proposition for entry into a joint activity (Clark 1996, pp. 203-205, pp. 331-334).

The previous discussion about coordination (proposals for entry into joint actions and alternative responses by proposal recipients) is similar to Winograd and Flores' (1986) state transition diagram (Fig. 8) for the possible states of people's conversation for action (Preece et al. 1994, p. 175).

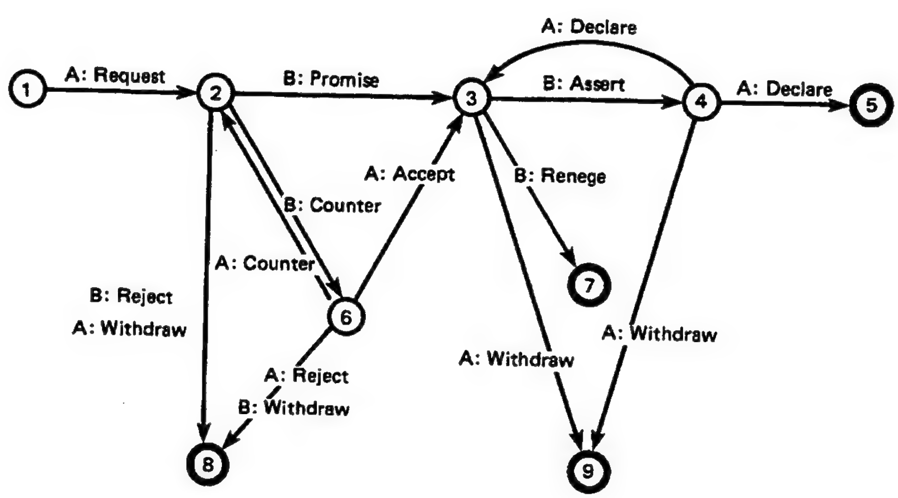

Fig. 8 — The basic conversation for action state transition diagram (Winograd and Flores 1986, p. 65). (Note that the states do not correspond to turn-taking, but only represent the different possible "states" for this type of conversation.)

If we can view a proposal for entrance into a joint activity as a kind of Winograd and Flores' "conversations for action," then we have a useful state transition diagram for analyzing people's joint project entrance coordination behaviors. Clark's alternative responses to entrance proposals would represent different paths through the Winograd and Flores' state transition diagram: "take-up with full compliance" could be a 1-2-3-4-5 path; "take-up with alteration" could be a 1-2-6-3-4-5 path; "decline" could be a 1-2-8 path; however "withdraw" has no comparative path. I propose that Winograd and Flores' state transition diagram for conversation for action has limited usefulness because of its failure to model the "withdraw" response option.

Coordination of joint activities takes time and effort to perform, so people use shortcuts whenever possible. Clark (1996, pp. 70-72) identifies two different kinds of coordination shortcuts. The first is explicit agreement. This is a planned future coordination that all participants commit to. For example, all participants can agree on the time, place, and format of their next meeting. This saves participants from having to dynamically coordinate part of the entrance into a future joint activity. The other kind of coordination shortcut is convention. Convention solves a recurring coordination problem by fixing a "standard" way to coordinate all future occurrences of a particular kind of coordination problem. Clark provides a useful example, "in America and Europe, placing knives, forks, and spoons on the table is a solution to the recurrent problem of what utensils to use in eating. In China and Japan, it is to place chopsticks" (Clark 1996, p. 70).

People use explicit agreement and convention to shortcut the coordination costs of interruption. For example, when people explicitly agree to a future meeting, they shortcut the need to interrupt each other to enter into that future joint activity. Also, if people can create a convention for meeting, they shortcut the coordination costs of interrupting each other for the entrance to all recurring meeting joint activities. For example, all participants agree to meet at a particular time and place on the second Tuesday of each month.

THEORETICAL CONSTRUCT(S) about people (Clark 1996):

P108. People must coordinate several issues to enter a successful joint activity: *agreement* to enter; *who* will participate; *what* will be the content of joint activity and the roles of participants; *where* and *when* the joint activity will take place; the joint purpose (*why*); and *how* to signal and transition boundaries.

P109. There are four requirements for the successful coordination of entrance into joint projects (and therefore requirements for successful interruption): (1) identification — participants must understand the nature of the proposed joint project; (2) ability — participants must be able to fulfill their roles in the proposed joint project; (3) willingness — participants must be willing to fulfill their roles in the proposed joint project); and (4) mutual belief — participants must each believe that all participants have successfully coordinated requirements 1, 2, and 3 and then 4 itself.

P110. People can respond to propositions for entrance into joint activities in a number of different ways. Four possible alternative responses to the same proposition are: (1) take-up with full compliance (comply fully with proposition as-is); (2) take-up with alteration (comply with variant of original proposition, i.e., decline proposition and counter-propose an altered version of the original); (3) decline (decline by indicating inability or unwillingness to comply); and (4) withdraw (withdraw totally without responding to proposal).

P111. People in U.S. English culture maintain a subtle informal agreement not to ignore each other.

P112. Coordination of joint activities takes time and effort to perform.

P113. People can shortcut the costs of coordinating entrance into joint activities by employing explicit agreement (for single future joint activities) or convention (for recurring future joint activities).

3 SYNTHESIS

Aims and Objectives

The aim of this section is to synthesize generally useful theoretical tools for the investigation of human interruption. No general tools exist yet for this research. This report uses the results of the preceding analysis section to create a general definition of human interruption and a supporting taxonomic tool for practical application.

The best way to make generally useful theoretical tools for research is to start with a general model of the topic. However, no general model of human interruption exists in the current literature, and building such a rigorous model is beyond the scope of this project. However, the theoretical constructs identified in the analysis section can be used as a proxy for a general model of human interruption. Together, these relevant theoretical constructs comprise a raw and jumbled conglomeration that is itself a useful substitute for a general model of human interruption. This substitute model is useful as a proxy for a general model of human interruption.

This section uses the results of Section 2 to synthesize theoretical tools that are generally useful for research about human interruption. Two tools are synthesized and presented here: (1) a general definition of human interruption with accompanying postulates and assertions and (2) a taxonomy of human interruption. This is a descriptive tool that exposes the important theoretical dimensions for analyzing and describing interruptions.

After reading this section, readers should be familiar with the theoretical tools presented here and should understand the claims of general utility of these tools and the tool's potential for practical application into the investigation of human interruption.

Overview

This report proposes a useful and unique theoretical tool for the investigation of human interruption — a general unifying definition of human interruption. This report uses the term "unifying" for its general definition of human interruption because this unique theoretical tool is general enough to bridge the semantic boundaries between several different fields of research. The general definition presented here can unify HCI research about user-interruption by supporting the generalization of theoretical models and experimental results across domains.

The analysis of relevant theory from the current literature identified 126 theoretical constructs of interruption (113 about people, 7 about tasks, 3 about interruptions, and 3 about contexts). This set of identified theoretical constructs forms a substitute for a general model of human interruption, because the component pieces are derived from very broad overview of relevant research domains. The extensive breadth of the analysis makes the resulting pile of theoretical constructs generally useful. This section uses this raw information to synthesize a general definition of human interruption and accompanying tools for practical investigation of human interruption.

This synthesis maximizes the general utility of the unifying definition of human interruption in four ways:

(1) it uses the maximum breadth depth of analysis results from the preceding section;
(2) it successfully identifies general common threads of theory across all the different theoretical perspectives from the various research fields analyzed;

(3) it uses those general concepts to synthesizes a definition of interruption and accompanying theoretical tools; and
(4) it excludes all nongeneral theoretical concepts from the synthesis of its general tools.

Motivation

Generally useful theoretical tools are necessary for the investigation of human interruption. No such tools exist. This section uses the results of the previous analysis section to synthesize a general, unifying definition of human interruption and an accompanying taxonomic tool for its practical application in research.

3.1 A General Unifying Definition of Human Interruption

Definition: *Human interruption is the process of coordinating abrupt change in people's activities.*

Postulate 1: This abrupt change involves one or more of a person's modes of activity: (1) cognition, (2) perception, or (3) physical action.

Assertion 1: This definition is most useful for investigating deliberate invocations of this process as attempts to cause meaningful effect(s).

Postulate 2: Interruption causes effects that are measurable with an acceptable level of measurement error.

Postulate 3: Interruption is accomplished with physical mechanisms in physical media. (Note, this supports postulate 2.) These physical mechanisms and media are identified in Section 2 and are modeled with the theoretical constructs of interruption presented there.

Postulate 4: Causal relationships exist between the state of several important dimensions of the process of interruption and the effects of the interruption. These process dimensions are the significant veins of descriptive theory contained in the proxy model of human interruption created in Section 2. These veins are the useful dimensions for investigating relationships between particular interruptions and their effects on people. (Note, see the Taxonomy of Human Interruption on p. 72.)

Assertion 2: It is possible to intentionally affect the consequences of interruption. The values of the dimensions of the interruption process can be deliberately controlled in order to influence the outcome of interruption events, i.e., its costs and benefits.

Assertion 3: The effects of user-interruption in HCI are directly related to the particular design chosen for the user interface of the system. The design of the user interface directly affects the states of dimensions of the interruption process and, therefore, causally affects the results of interrupting the user.

Assertion 4: The theoretical taxonomic tool provided in this section is useful for applying the general unifying definition of interruption presented here. This taxonomy of human interruption is especially useful for investigating user-interruption in HCI.

This general unifying definition of human interruption is a tool. I assert that it is generally useful for the investigation of human interruption. Each part of this definition expresses some theoretical concept of human interruption in a way that is generally applicable.

3.1.1 Human Interruption: a Process of Coordination

Several theoretical constructs say it is useful to consider interruption as more than just a thing or a sign or token that people use. Interruption is an entire process. It involves the who, what, where, when, why, and how of each stage in the generation, transmission, reception, comprehension, and reaction to an interruption event. Other theoretical constructs say that interruption also includes how people coordinate transitions between the different stages of interruption event.

For example, the theoretical construct C2 (p. 53, from Section 2.13, Language Use in Linguistics) says that "language cannot be separated from its context of use." Therefore, any definition of interruption must include reference to the total process of interruption. Theoretical constructs P51 (p. 33, from Section 2.6, Human-Human Discourse), and P80 (p. 42, from Section 2.11, Interactional Sociolinguistics of Politeness), promote the usefulness of the idea of a "communication act" that embodies more than just the communication message. A communication act is three things: a meaning, an expression, and a channel of conveyance. Another useful variant of the concept comes from theoretical construct P101 (p. 60, from Section 2.13, Language Use in Linguistics) — signaling theory. It says that signals are more than just the signs they pass. Signals are signs, methods of signaling, and the cognitive processes of sign interpretation.

Interruption is also how people coordinate the interrelationships among the various parts of the interruption process. Theoretical construct P93 (p. 53, from Section 2.13, Language Use in Linguistics) says that joint activities (like interruption) are accomplished with a "fabric of coordination created by the participants." Theoretical construct P50 (p. 31, from Section 2.6, Human-Human Discourse) says that communication acts are more than just their parts but must be coordinated by the people involved. Theoretical constructs P108 and P109 (p. 64, from Section 2.13, Language Use in Linguistics) say that there are several elements and points of agreement that people must coordinate for their successful entry into a joint activity (i.e., interruption).

The definition of human interruption presented here has a good analogy in the event models of programming languages. Consider the Java programming language's event model (AWT 1.0) (Chan and Lee 1997, pp. 458-492). This analogy is useful for illustrating the claim that human interruption is more than just the sign that carries that interruption.

Human interruption is somewhat like user interface events in Java. To investigate user interface events in Java (or to investigate human interruption), it is not useful to only look at Event objects. A productive investigation must examine all the parts of the event model and study how all those pieces coordinate in time. In Java, user interface events are part of a larger event model. Instances of Event objects are generated because of human users interacting with a Java program's graphical component through an interaction device (e.g., a mouse or keyboard). After an Event object is generated, it is translated into the appropriate graphical context and delivered to the appropriate graphical component object. The event continues to be translated and delivered up the component hierarchy (visual hierarchy) until some component handles it or until it passes through the entire component hierarchy. The component objects in the component hierarchy receive Event objects and can be programmed with methods to handle those events. If programmed to do so, a component object's event-handler method(s) will be called and passed Event objects. A component object's event handler method identifies the Event objects it receives and uses their identity to choose and make appropriate reactions.

3.1.2 Human Interruption: Abrupt Change

The theoretical constructs identified in the analysis section do not provide a quantitative expression of how quickly interruptions happen (such a quantification would be very interesting). Instead, the word

"abrupt" here distinguishes interruption from other kinds of gradual progressions of change that people experience in their activities. Theoretical construct P14 (p. 14, from Section 2.2, Multitasking in HCI) says that it is useful to model people's ability to quickly switch between different activities. Theoretical construct P21 (p. 17, from Section 2.3, Multitasking in Linguistics) says that it is useful to model people's cognitive behavior of dynamically modifying and changing their behavior while they are making it. The word abrupt in this report's definition of human interruption is meant to portray interruption as something that happens quickly and dynamically in real time.

3.1.3 Human Interruption: a Change in People's Activities

The simple intuitive explanation is that people have to be doing something before they can be interrupted to start doing something else. Theoretical constructs P65 and P67 (p. 37, from Section 2.8, Psychology of Human Attention) say that it is useful to model all of people's changes in focused attention as changes in the processing stream that currently is executing in the person's focus of consciousness. People perform activities that change. Theoretical construct P97 (p. 54, from Section 2.13, Language Use in Linguistics) says it is useful to model human-human behaviors (like interruption) as joint activities that have stages that change over time. People also use interruption to perform several simultaneous, intermittent, nested, and dynamically changing joint activities at the same time (theoretical construct P98 (p. 54, from Section 2.13, Language Use in Linguistics)).

3.1.4 Usefulness of the Definition for Practical Research

The general unifying definition of human interruption presented here affords great research questions. This power for motivating well-constructed research questions is one of the most useful contributions of this general definition. Here are some examples:

- What are the stages in the process of interruption?
- How do people coordinate the process of interruption?
- Of the people involved, who does what parts of the coordination?
- When do people accomplish the different stages and coordinations of interruption?
- Why are people changing theirs, and/or other people's activities, i.e., what is the meaning of an interruption?
- How and why do people carefully design their interruption expressions?
- What channels of conveyance do people use for interruption, and how does the channel used affect the interruption process?
- What kinds of human activities are changed through interruption?
- What are the effects or costs and benefits of interruption of human activities?

Investigation of these questions is directly supported by numerous theoretical constructs from the analysis section of this paper. Many of these theoretical constructs do not directly support the unifying definition itself, because they say how interruptions work but not what they are. However, the collection of theoretical constructs is broad enough to be a generally useful tool for both general definition and practical research.

The Taxonomy of Human Interruption (Table 9 (p. 73)) is a practical synthesis of the theoretical constructs identified in the analysis section. This taxonomy describes and categorizes the useful dimensions of theoretical ideas for practical investigations of human interruption.

3.1.5 Generalizability of the Definition for Various Fields of Research

It is possible to create theoretical tools that allow researchers to share and generalize well-controlled research results across domain boundaries. I claim that the definition I present here is generally useful. I support this claim by showing how this general definition of human interruption can be applied to each one of the various research domains analyzed in the analysis section of this paper. I restate the general definition of human interruption ("human interruption is the process of coordinating abrupt change in people's activities") in terms of each field of research and give examples of how this general definition can help researchers form good questions.

Colloquial Meaning (see Section 2.1 on p. 8)

(The field of etymology views interruption as "a word of the English Language.")

The general definition presented here is a new, alternative definition for the common English meaning of interruption. It could help etymologists investigate potential improvements to existing dictionaries. It is possible that this general definition of interruption describes useful relationships of meaning that are not yet embodied in English dictionaries. For example, the general definition promotes the idea of interruption as a process of coordination.

Multitasking in HCI (see Section 2.2 on p. 9)

(This field views interruption as "an unanticipated request for task switching during multitasking.")

Interruption is the process of coordinating task switching in the human activity of multitasking in HCI. The general definition could help researchers form good questions about the process of coordinating task switching in multitasking and how people's multiple activities are affected by interruption.

Multitasking in Linguistics (see Section 2.3 on p. 15)

(This field views interruption as "an unanticipated request for topic switching during asynchronous parallelistic human-computer interaction.")

Interruption is the process of coordinating asynchronous parallelistic topic switching during the human activity of linguistic interaction in HCI. The general definition could help researchers form good questions about the process of coordinating topic switching in people's asynchronous parallelism and how people's parallel linguistic interactions are affected by interruption.

Multitasking in Situational Awareness (see Section 2.4 on p. 18)

(This field views interruption as "an event that threatens the delicate balance between situational awareness and focused activity, i.e., the reception of unpredictable new data.")

Interruption is the process of coordinating multitask switching and comprehension of new, incoming information during the human activity of situational awareness during multitasking. The general definition could help researchers form good questions about the process of coordinating task switching and comprehension of new incoming information and how the multiple activities are affected by interruption.

Management of Semiautonomous Agents (see Section 2.5 on p. 25)

(This field views interruption as "a costly side effect of delegating tasks to intelligent agents.")

Interruption is the process of coordinating interaction with a semiautonomous agent during any other human activity. The general definition could help researchers form good questions about the process of coordinating intermittent interaction with a software agent and how people's agent management and their other activities are affected by interruption.

Human-Human Discourse (see Section 2.6 on p. 30)

(This field views interruption as "an example of human-human discourse that can be represented and analyzed with the theory of discourse analysis.")

Interruption is an example of a coordination process in the human activity of human-human discourse. The general definition could help researchers form good questions about the process of coordinating interruption in discourse and how people's discourse is affected by interruption.

Human-Human Dialogue (see Section 2.7 on p. 35)

(This field views interruption as "a very common and normal part of human-human dialogue behavior.")

Interruption is an example of a common coordination process in the human activity of human-human dialogue. The general definition could help researchers form good questions about the process of coordinating interruption in dialogue and how people's dialogue is affected by interruption.

Psychology of Human Attention (see Section 2.8 on p. 36)

(This field views interruption as "the method by which a person shifts their focus of consciousness from one processing stream to another.")

Interruption is the process of coordinating shifts of people's processing streams in their focus of consciousness during the human activity of attention. The general definition could help researchers form good questions about the process of coordinating shifts in people's focus of consciousness and how people's attentional activities are affected by interruption.

A Metaphor of Cognitive Momentum (see Section 2.9 on p. 39)

(This informal perspective views interruption as "something that extinguishes a person's cognitive momentum when they are performing concentrated work on a complex task.")

Interruption is the process of coordinating transitions between different human tasks. The general definition could help people form good informal questions about the process of transitioning between tasks and how shifting between activities affects people's cognitive momentum.

Social Psychology of Conversation (see Section 2.10 on p. 40)

(This field views interruption as "a violation of people's conversational rights.")

Interruption is the process of coordinating the control of the human dialogue process during the human activity of adjusting people's social status. The general definition could help researchers form good questions about the process of coordinating the control of people's social status and how people's activity of managing social status is affected by interruption.

Interactional Sociolinguistics of Politeness (see Section 2.11 on p. 41)

(This field views interruption as "a face-threatening act.")

Interruption is the process of coordinating FTAs (face-threatening acts) in ways to mitigate the severity of those threats during the human activity of linguistic interaction in social contexts. The general definition could help researchers form good questions about the process of coordinating FTAs and how people's activities of satisfying face-wants are affected by interruption.

Simultaneous Speech in Linguistics (see Section 2.12 on p. 50)

(This field views interruption as "a disruptive type of simultaneous speech.")

Interruption is the process of coordinating simultaneous speech during the human activity of human-human linguistic interaction. The general definition could help researchers form good questions about the process of coordinating simultaneous speech and how people's linguistic activities are affected by interruption.

Language Use in Linguistics (see Section 2.13 on p. 52)

(This field views interruption as "a proposal for an entry into or exit out of a joint activity.")

Interruption is the process of coordinating transitions between stages in people's human-human joint activities. The general definition could help researchers form good questions about the process of coordinating transitions between stages in people's joint activities and how people's joint activities are affected by interruption.

3.2 Taxonomy of Human Interruption

The general definition of interruption presented above is useful as a tool for forming good research questions about human interruption. The taxonomy of human interruption is a practical tool for answering those questions.

Investigation of human interruption can be a difficult business. Interruption of people is a complex process. An example is the design of user interfaces for the HCI of user-interruption. System designers cannot do a good job of specifying system requirements with existing theoretical tools about human interruption. It is difficult to objectively describe all the significant parts of this process and their interrelationships. This difficulty makes it hard to produce good user interface design for systems that interrupt their users.

This report presents a taxonomic research tool that augments the utility of the general unifying definition. This taxonomy of human interruption is a tool for describing instances of human interruption. It proposes useful categories for analyzing cases of human interruption. These categories are synthesized directly from the large set of theoretical constructs that describe how the interruption process works. These

theoretical constructs collectively identify the most useful dimensions of theory for investigating human interruption.

Table 9 — Taxonomy of Human Interruption

Descriptive Dimension of Interruption	Example Values
source of interruption	self [human]; another person; computer; other animate object; inanimate object. (See Table 10 (p. 74) for examples.)
individual characteristic of person receiving interruption	state and limitations of personal resource (perceptual, cognitive, and motor processors; memories; focus of consciousness; and processing streams); sex; goals (personal, public, joint); state of satisfaction of face-wants; context relative to source of interruption (common ground, activity roles, willingness to be interrupted, and ability to be interrupted). (See Table 11 (p. 74) for examples.)
method of coordination	real-time negotiation; mediation; precoordination (by explicit agreement for a one-time interruption, or by convention for a recurring interruption event). (See Table 12 (p. 75) for examples.)
meaning of interruption	alert; stop; distribute attention; regulate dialogue (metadialogue); supervise agent; propose entry or exit of a joint activity; remind; communicate information (illocution); attack; no meaning (accident). (See Table 13 (p. 75) for examples.)
method of expression	physical expression (verbal, paralinguistic, kinesic); expression for effect on face-wants (politeness); signaling type (by purpose, availability, and effort); metalevel expressions to guide the process; adaptive expression of chains of basic operators; intermixed expression; expression to afford control. (See Table 14 (p. 77) for examples.)
channel of conveyance	face-to-face; other direct communication channel; mediated by a person; mediated by a machine; meditated by other animate object. (See Table 15 (p. 79) for examples.)
human activity changed by interruption	internal or external; conscious or subconscious; asynchronous parallelism; individual activities; joint activities (between various kinds of human and nonhuman participants); facilitation activities (language use, meta-activities, use of mediators). (See Table 16 (p. 79) for examples.)
effect of interruption	change in human activity (the worth of this change is relative to the person's goals); change in the salience of memories; change in awareness (metainformation) about activity; change in focus of attention; loss of willful control over activity; change in social relationships; transition between stages of a joint activity. (See Table 17 (p. 81) for examples.)

Note: see the following tables for examples of the categories of analysis afforded by this taxonomy.

The following tables provide examples of interruptions for each of the dimensions in the Taxonomy of Human Interruption (Table 9):

Table 10 — Source of Interruption

Source of Interruption	**Example**
self [human]	While writing, I realize that I need to stop and rephrase my last sentence.
another person	Answer ringing telephone and hear "Hello Ms. Jones, you have been preapproved to receive our gold MasterCard!"
computer	While trying to save a document, the computer presents a modal dialogue box that says, "Not enough memory to complete last command. Please quit applications or close windows."
other animate object	Your dog walks over and presents its empty water bowl.
inanimate object	Avalanche.

Table 11 — Individual Characteristics of Person Receiving Interruption

Individual Characteristic	**Example**
personal resource	I am trying to remember a phone number. However, I am interrupted with something else that also requires my memory resources — the original phone number is lost.
sex	A female is interrupted by a male. She feels that her gender role does not give her the same right as a male to aggressively fight off the interruption.
goals	I am talking long distance to a hotel reservation clerk. We have the joint goal of getting me a room reserved and prepaid. My call-waiting clicks, telling me that someone is trying to interrupt me. I ignore the interruption — I decide that my joint goal with the hotel clerk is too important to risk failure because of an interruption.

Table 11 — Individual Characteristics of Person Receiving Interruption (Continued)

Individual Characteristic	Example
face-wants	I perceive that I am very busy working. My interruptor understands that my negative face-wants (not to be impeded) are especially high now, so they design the expression of their interruption to provide me good redress for their threat to my negative face. "I don't suppose that I might interrupt you now."
context relative to source	I am much more willing to be interrupted by my supervisor at work than I am willing to be interrupted by a total stranger.

Table 12 — Method of Coordination

Method of Coordination	Example
real-time negotiation	I am interrupted while writing. Stan walks into my office and says, "Excuse me, I need to talk to you." I have four possible responses to Stan's proposal for entry into a joint activity: accept, accept with alteration, reject, or withdraw. I respond, "Just give me a minute to finish my thought.... OK?"
mediation	Sarah wants to interrupt the Chinese Commodities Office for information. She calls her secretary on the intercom, "Please call the Chinese Office and ask them for their current price on rice."
precoordination (explicit agreement)	"I'll meet you for lunch tomorrow at 12 o'clock outside of Tony's restaurant."
precoordination (convention)	"We'll meet in this conference room at 1:30 pm the first Monday of every month."

Table 13 — Meaning of Interruption

Meaning of an Interruption	Example
Alert	
divert attention, i.e., switch the processing stream in a person's focus of consciousness	A driver stopped at a traffic light and "beeps" their horn to divert the attention of the driver in front of them to the green traffic light.
warn	"Duck!"
announce the occurrence of an event	"Ladies and gentlemen, the show is about to begin."

Table 13 — Meaning of Interruption (Continued)

Meaning of an Interruption	Example
Stop	
arrest perception	Turn off the lights
arrest cognition	Say to yourself, "It's only a movie."
arrest external behavior	In the SAT exam, "Time is up — everyone put down your pencil."
Distribute Attention	
multitasking	A person has adopted a policy of switching between tasks in order to perform more than one task at a time, "It's time to work on task 'x' for a while."
maintaining situational awareness	A person has adopted a policy of switching their attention between contexts in order to maintain awareness of several things at a time, "It's time to see how 'x' is doing."
Attack	
influence social relationships	Assert dominance over the current speaker in a social group by wresting the groups attention from the current speaker to oneself.
Metadialogue for Dialogue Regulation	
metacommunication for dynamically adjusting an activity to maintain appropriateness of efforts within a changing context	I'm telling a story to another person. I suddenly realize, based on my listener's facial expression, that I have told them this same story before. So I interrupt myself and apologize.
facilitate speed of interaction	"The doctor will see you now."
request a turn in a conversation	I want to ask a question of an employee of a hardware store who is currently talking to another customer, "Excuse me for interrupting, may I speak with you next?"
dialogue regulation	Radio talkshow, "Excuse me, Mr. Jones, but we only have 30 more seconds of air time."
begin or end a conversation	"Excuse me, I need to talk to you."
Supervise Agent	
request for supervision or coordination by an agent to a supervisor	"Here is the report you requested."
request for delegation or coordination by a supervisor to an agent	"Calculate the Robertson's total federal taxes for 1996."
commanding	"Drop and give me 20 push-ups."
get progress report	"How is your dissertation coming?"

Table 13 — Meaning of Interruption (Continued)

Meaning of an Interruption	Example
Manage a Joint Activity	
propose an entry into a joint activity and communicate the proposer's identity, ability, willingness, and need for mutual belief	Ted shows up in person at my office and asks, "Frank, I need to talk to you. Do you have a minute right now?"
propose an exit from a joint activity	"Excuse me, but I need to leave now to go to the dentist."
Reminder	
satisfy a prearranged interruption event of either explicit agreement, or convention	Jason and I prearranged a meeting in his office today at 2 p.m. I arrive in his office at 2 p.m., "Hi, shall we begin?"
Illocution	
education	Two students are talking during physiology class. The professor walks over and talks in their faces, "The human hand has three bones in each finger ...."
Accident (no meaning whatever)	
passing in a hallway	Two pedestrians are approaching each other in a hallway. They accidentally both choose the same side of the hallway to pass each other. Their progress is interrupted until they can coordinate how to get past each other.

Table 14 — Method of Expression

Expression Of An Interruption	Example
Physical Expression	
verbal (vocal verbal)	Say, "Excuse me, please — I need to interrupt you now."
paralinguistic (vocal nonverbal)	Clear throat loudly, "ugh um."
kinesic (nonvocal nonverbal)	Make the time out "T" signal, like in a football game.
Expression for Effect on Face-Wants	
bald-on-record nonpoliteness	The airplane blasts a loud buzzer to alert the pilot of a fire (note: see also Table 3 (p. 46) for examples of politeness expressions).
positive politeness	"Hey, your idea worked great! Let me tell you what happened ...."

Table 14 — Method of Expression (Continued)

Expression Of An Interruption	Example
negative politeness	"I would be very grateful if you would allow me to interrupt you now."
off-record politeness	Stare at the person you want to interrupt.
Signaling Type (by purpose, availability, and effort)	
Description	Spoken words usually easy in face-to-face interaction — "I need to interrupt you now." (Note: see also Table 7 (p. 58) for examples of signaling expressions.)
Indication	In a noisy room and several yards away, indication can be easier than description — point at a person to get their attention and indicate that you want to interrupt them
Demonstration	In relating a message to someone, it can be much easier to demonstrate than to try to explain the speakers tone of voice — "Your mom said, 'get William off the telephone.'" [impersonation of mother's angry voice.]
Metalevel Expressions to Guide the Process	
back-channeling	While I talk to someone, they frequently say things like, "Yea," "I see," "Um hm." These interruption tell me that my listener understands what I'm saying.
regulation of turn-taking	While I talk to someone, they say, "but...." This interruption tells me that the listener wants a turn to speak.
directing attention	I am asking Jane where she left my diskette. In the middle of my speech act, Jane points to a drawer.
select listener	While I am talking to Randy, Bill says, "Daniel" [my name]. Bill has interrupted me to select me as the listener for a joint project he wants to enter.
Adaptive Expression of Chains of Basic Operators	
express chains of basic operators — dynamically planned in parallel and expressed serially	I constantly monitor the dynamic effect caused by my communication act as I express it to my audience. I dynamically replan the chain of basic operators as I execute them to adapt my planed meaning and expression to conform to the changing context of interaction.
Intermixed Expression	
composite signals	Simultaneous: hand chopping gesture (as a demonstration signal to mean a request for interruption); "Please excuse me, will you hand me that?" (as a description signal); and eye gaze fixed to the object I want (as an indication signal).

Table 14 — Method of Expression (Continued)

Expression Of An Interruption	Example
Expression to Afford Control	
affordances for choices in responses to interruption	Express interruption to allow interruptee to choose among: accept, accept with alteration, reject, or withdraw.
affordances for defenses to interruption	Express interruption to allow interruptee to fight off interruption if they want to reject it. Allow them to: mark the interruption as a violation of their right to speak, eclipse the interruption, or ignore the interruption

Table 15 — Channel of Conveyance

Conveyance of an Interruption	Example
face-to-face	Walk up and present myself in person and say, "Excuse me."
other direct communication channel	Call on an intercom system and say "Hi, this is Robert, I need to talk to you for a moment."
mediated by a person	I'm giving a guest presentation at a new place, and I ask my host to quiet the audience because I'm ready to begin.
mediated by a machine	I leave a message for you on your answering machine
meditated by other animate object	A burglar has broken into my house — I send the dog to interrupt him.

Table 16 — Human Activity Changed by Interruption

Human Activity Changed by Interruption	Example
individual activities	I am drawing a picture of a landscape on a piece of paper.
internal	[drawing example, cont.] I do more than one internal activity simultaneously: I perceive my environment; I compare proportions of objects as I set them down on paper; I interpret the colors; I decide which aspects of the scene to emphasize; I day dream about a movie I saw.
external	[drawing example, cont.] I hold the paper in place with one hand and make a mark with the pencil in my other hand.
conscious	[drawing example, cont.] I consciously attend to the relative size of one object in the foreground.

Table 16 — Human Activity Changed by Interruption (Continued)

Human Activity Changed by Interruption	Example
subconscious	[drawing example, cont.] I subconsciously attend to many things: I listen for sounds of approaching animals; I monitor how much sun I'm getting; I evaluate the realism of the marks I make; I monitor how fatigued my back muscles are becoming; I shift my eye gaze to different areas of the scene.
asynchronous parallelism	[drawing example, cont.] I cycle the focus of my external actions to project my several internal activities one at a time. I accomplish this with a pattern of sharing my focus of consciousness among several processing streams.
Joint Activities	
human-human	I am at the check-out counter of the grocery store buying food. I create a joint activity with the check-out clerk.
human-computer (one of each)	I am writing an article on a microcomputer using word-processing software.
human-computer (more than one of each)	I work in a group of people on a network of computers using a digital video conferencing system and computer-supported cooperative work (CSCW) groupware.
Facilitation Activities	
language use	The act of using language is itself a kind of activity. The activity of language use allows us to perform other joint activities.
meta-activities	While I am interacting with another person, he or she and I are also performing the joint activity of maintaining common ground. Jim and I are performing the joint activity of social conversation during lunch. We make back-channeling communication acts during our conversation as a meta-activity to facilitate the success of our conversation.
use of mediators	The presidents of the U.S. and Russia are meeting. They employ translators to facilitate communication between English and Russian.

Interruptions can have good and/or bad effects. The worth of the effects of interruption are relative to the goals of the participants. For example, an airplane pilot has the goal of not crashing the airplane. If a pilot becomes completely focused on the task of fixing a broken light bulb, then an appropriate interruption would be good. An interruption could change the pilot's light-bulb-fixing activity and shift their attention to the airplane's altitude. This effect could save the lives of everyone on board. This interruption helps the pilot accomplish their goal of not crashing.

However, interruptions can also be bad. If a pilot is interrupted during the act of physically landing the plane, they could crash. An interruption of an accidental knock on the head could change the pilot's activity of landing the plane. This interruption prevents the pilot from accomplishing their goal of not crashing.

Table 17 — Effect of Interruption

Effect of Interruption	Example
change in human activity	An interruption substitutes one activity for another. The value of this substitution depends on whether it advances the participants' goals.
change in the salience of memories	An interruption reduces the salience of some memories and increases the salience of others. This change can help and/or hinder participants in accomplishing their goals.
change in awareness (metainformation) about activity	People maintain subtle metainformation about their activities. They use this metainformation to dynamically adjust their actions. However, if a person is interrupted and changes activities, they can become disconnected from metainformation about their previous task. This loss of awareness about the progress of the first task can result in a lag of dynamic behavior when resuming it.
change in focus of attention	An interruption switches a person's processing stream in their focus of consciousness. The worth of this change depends on the participants' goals.
loss of willful control over activity	People have "back doors" to their attention resources. An interruption can be expressed so as to immediately change a person's activity without their willful decision to allow it.
change in social relationships	Interruption can be a sign of social power. If a person allows themself to be interrupted, the interruptor can be perceived by all participants to have exerted social control.
transition between stages of a joint activity	Interruption is the mechanism for bridging the boundaries of joint activities. An interruption is a use of language to coordinate such a transition.

Two appendices are provided as aids for identifying domains of literature relevant to particular research contexts. Appendix A presents an index of domain perspectives of interruption and can be useful for identifying relevant fields of research. Appendix B presents an index of theoretical constructs of interruption and can be useful for identifying common concepts across domains.

Appendix A

INDEX OF DOMAIN PERSPECTIVES: IDENTIFYING RELEVANT FIELDS OF RESEARCH

This index is a tool for discovering which domains and topics of research should be relevant for investigating interruption from a given perspective. Given a domain perspective or approach to a human-computer interaction (HCI) design problem with user-interruption, this index can be used to identify relevant domains and topics of published literature.

Interrupting people can cause critical and even life-threatening effects. The critical topic of user-interruption requires a comprehensive user-interface design solution. However, comprehensive solutions require comprehensive identification and integration of all relevant published research results and theoretical tools from all sources of current literature. This index can be useful in identifying relevant domains within the current literature.

Table A1 — Index of Domain Perspectives

Domain Perspective	Sources of Useful Research Results and Theory
Colloquial Meaning (Section 2.1 on pg 8)	etymology
Multitasking in HCI (Section 2.2 on pg 9)	multitasking; computer-supported cooperative work (CSCW); human-computer interaction (HCI); cognitive psychology; cognitive modeling
Multitasking in Linguistics (Section 2.3 on pg 15)	linguistics; cognitive psychology; HCI
Multitasking in Situational Awareness (Section 2.4 on pg 18)	situational awareness; attention; psychology; memory; dual-tasking
Management of Semiautonomous Agents (Section 2.5 on pg 25)	task off-load aids; supervisory control; intelligent software agents; multitasking
Human-Human Discourse (Section 2.6 on pg 30)	discourse analysis; communication acts
Human-Human Dialogue (Section 2.7 on pg 35)	dialogue
Psychology of Human Attention (Section 2.8 on pg 36)	attention; memory; cognitive psychology; perception
A Metaphor of Cognitive Momentum (Section 2.9 on pg 39)	informal literature on multitasking in office environments
Social Psychology of Conversation (Section 2.10 on pg 40)	sociology; social psychology; metacommunication; dialogue
Interactional Sociolinguistics of Politeness (Section 2.11 on pg 41)	interactional socio-linguistics; discourse analysis
Simultaneous Speech in Linguistics (Section 2.12 on pg 50)	discourse analysis; dual-tasking; dialogue
Language Use in Linguistics (Section 2.13 on pg 52)	linguistics; dialogue; signaling; signs; cognitive psychology; discourse analysis

Note: this index does not represent every possibility. Instead, this index cites only those topics and classes of literature that I found useful for writing the survey of theory for this report.

Appendix B

INDEX OF THEORETICAL CONSTRUCTS: IDENTIFYING COMMON CONCEPTS ACROSS DOMAINS

The interruption of people is a common phenomenon that occurs in several domains of research. I have identified a large set of theoretical constructs about this phenomenon from several diverse domains of published literature (126 identified theoretical constructs). However, it is difficult to use such a large set of theoretical constructs without an indexing aid. This Index of Theoretical Constructs provides such an index for finding all relevant theoretical constructs.

Some theoretical concepts cut across different fields of research in the published literature. Their ubiquitousness makes it difficult to locate all relevant research in the current literature. This index is a tool for easily indexing all the theoretical constructs of interruption identified in this report by the theoretical concepts to which they apply.

This index also categorizes theoretical constructs by whether they represent declarative or procedural information. Declarative theoretical constructs describe structures and how they function, i.e., "People have a single focus of consciousness; and this is how they switch processing steams into and out of it ...." Procedural theoretical constructs describe how the structures are employed to perform actions, i.e., "People accomplish dual-tasking by continuously switching their attention between the two tasks."

Table B1 — Index of Theoretical Constructs

Theoretical Construct	declarative theoretical constructs	procedural theoretical constructs
PEOPLE	P6 (pg 9); P10 (pg 12); P14 (pg 14); P35 (pg 24)	P13 (pg 14); P16 (pg 15); P24 (pg 19)
Cognition	P9 (pg 10); P15 (pg 14); P74 (pg 39)	P11 (pg 12); P12 (pg 12); P75 (pg 39)
memory	P26 (pg 21); P27 (pg 21); P28 (pg 22); P29 (pg 22); P30 (pg 23); P31 (pg 23); P32 (pg 23); P33 (pg 23)	P34 (pg 23); P36 (pg 24)
attention	P37 (pg 25); P38 (pg 25); P39 (pg 25); P60 (pg 37); P61 (pg 37); P62 (pg 37); P63 (pg 37); P64 (pg 37); P65 (pg 37); P66 (pg 37); P67 (pg 37); P72 (pg 39); P73 (pg 39)	P68 (pg 38); P69 (pg 38); P70 (pg 38); P71 (pg 39)
Perception		P25 (pg 20)
Motor	P7 (pg 9); P8 (pg 9)	
Purposes	P1 (pg 8); P2 (pg 8); P3 (pg 8); P4 (pg 9)	P5 (pg 9)
social relationships	P80 (pg 42); P82 (pg 42); P83 (pg 43); P86 (pg 49)	P76 (pg 40); P77 (pg 40); P78 (pg 41); P79 (pg 41); P81 (pg 42); P84 (pg 43); P85 (pg 49); P87 (pg 49); P88 (pg 50)
joint activities	P94 (pg 53); P95 (pg 53); P96 (pg 54); P97 (pg 54); P98 (pg 54); P99 (pg 54); P100 (pg 60); P108 (pg 64); P109 (pg 64)	P93 (pg 53); P110 (pg 64); P111 (pg 65); P112 (pg 65); P113 (pg 65)
communication	P17 (pg 17); P18 (pg 17); P19 (pg 17); P20 (pg 17); P21 (pg 17); P22 (pg 17); P52 (pg 33); P53 (pg 33); P101 (pg 60); P102 (pg 60); P103 (pg 60); P104 (pg 60); P105 (pg 60)	P23 (pg 17); P49 (pg 31); P50 (pg 31); P51 (pg 31); P54 (pg 33); P55 (pg 33); P56 (pg 33); P57 (pg 33); P58 (pg 34); P59 (pg 36); P89 (pg 51); P90 (pg 52); P91 (pg 52); P92 (pg 52); P106 (pg 60); P107 (pg 61)
work	P40 (pg 26); P41 (pg 26); P43 (pg 27)	P42 (pg 26); P44 (pg 27); P45 (pg 27); P46 (pg 29); P47 (pg 29); P48 (pg 29)
TASKS	T1 (pg 10); T2 (pg 15); T3 (pg 19); T4 (pg 24); T7 (pg 26); T6 (pg 26)	T5 (pg 24)
INTERRUPTIONS	In1 (pg 8); In3 (pg 50)	In2 (pg 15)
CONTEXTS	C1 (pg 29); C2 (pg 53); C3 (pg 55)	

Note that some theoretical constructs have a mix of declarative and procedural information. I have had to decide how to pigeon-hole these theoretical constructs into single categories. Readers will disagree with some of my decisions. Therefore, this index will be most useful if the reader pursues a broad range of related categories.

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